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# GLASS FIBER REINFORCED PLASTIC PRESSURELESS TIRE (U)

FINAL REPORT

U.S. ARMY TANK AUTOMOTIVE COMMAND LABORATORIES

DEC 16 1969


by James C. Hood

OWENS-CORNING FIBERGLAS CORP.



Date: October, 1969

Contract No. DAAE 07-67-C-4319


TACOM

VEHICULAR COMPONENTS & MATERIALS LABORATORY

U.S. ARMY TANK AUTOMOTIVE COMMAND Warren, Michigan



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Owens-Corning Fiberglas Corporation
Technical Center
Granville, Ohio 43023

## ABSTRACT

The program sought to provide adequate data on which to base a judgment of the probability of success in producing a satisfactory glass fiber reinforced plastic pressureless tire by the filament winding method. The tire sought represents an entirely new and unique concept in automotive tires, and would be impossible to deflate.

A process was developed to produce a preliminary model of a 7.00 x 16 tire. Several tire configurations were wound and tested statically, and dynamically on an indoor wheel at USATACOM. The last carcass made ran for 239 miles at 850 pounds load; most of the test was conducted at 40 miles per hour.

The feasibility of a glass fiber reinforced plastic pressureless tire was demonstrated.

## FOREWORD

This report covers the work performed by Owens-Corning Fiberglas Corporation, Granville, Ohio, under U. S. Army Tank - Automotive Command (USATACOM) Contract No. DAAE 07-67-C-4319, during the period June, 1967 through March, 1969.

The contract was initiated by the Rubber Products Branch of Materials Division under Request No. PR EM-7-6R-666-01-EH-EH. The Contract was under the technical direction of Mr. Roger Kirk (AMSTA-BMR) of the Rubber Products Branch.

The program was conducted by the Reinforced Plastics Market Development Department of the Owens-Corning Fiberglas Corporation Technical Center, Granville, Ohio. Mr. James C. Hood was the principal investigator, assisted mainly by Mr. P. Douglas Lyle.

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## I. INTRODUCTION

In response to a government requirement for "a tire which maintains or exceeds present wear and ride characteristics and is impossible to deflate", a unique concept for a glass fiber reinforced plastic (GFRP) tire was proposed. This tire can support the vehicle weight by virtue of the strength and rigidity of the GFRP material, without any air pressure.

The concept involves making a complete toroidal carcass from GFRP by filament winding on a water disintegratable mandrel. After heat curing the carcass, the mandrel would be washed out through small holes or slits in the carcass. Then a protective rubber covering would be molded in place over the entire surface of the GFRP carcass and a rubber tread applied. The rim would be split and molded to fit the tire inside diameter (ID), or would be made an integral part of the tire.

GFRP can be fabricated to provide a wide range of finished laminate properties by varying the types and forms of glass fiber reinforcement and plastic matrix. GFRP structures are unique in the large degree of anistropy that can be designed into them.

Of prime importance to the making of a satisfactory GFRP tire is the availability of a wide range of flexibility (modulus) in these materials. For practical purposes, a modulus anywhere between $1.5 \times 10^6$ psi and $8.0 \times 10^6$ psi can be obtained in one direction. In general, GFRP can be made much more flexible than metal, or just a little more flexible, and the higher modulus varieties can be made with a very high strength/weight ratio. Compared to metal, the GFRP is elastic to a higher percentage of its ultimate strength, will not dent, and is more impact resistant, particularly in the filament wound form. The strength and modulus of GFRP can be oriented in the directions required to sustain loads most efficiently. In addition, GFRP has vibration damping characteristics that are superior to many other materials. The approach to making a satisfactory GFRP tire consists primarily of obtaining the proper stiffness by adjusting the material composition and wall thickness, while retaining the highest possible strength properties.

For several years, Owens-Corning Fiberglas Corporation conducted in-house research directed toward demonstrating preliminary feasibility of a GFRP tire. The in-house program was divided into five major parts:

(1) Investigation of flexural strength and fatigue life of hollow GFRP cylinders.

(2) Construction of a machine to filament wind toroids.
(3) Development of prepreg package and disintegratable mandrels.
(4) Development of toroid winding technique.
(5) Development of rubber bonding technique.

Thirty-five 6 3/8-inch diameter by 8-inch long cylinders were filament wound on available mandrels using various glass fiber rovings and epoxy resins. The mandrel size approximated the diameter of the tire of interest (7.00 - 16). The cylinder walls were about 1/8 inch thick and designed to support about 1000 pounds at one inch deflection on the diameter. The load/deflection relationship was measured by loading a cylinder on its side between flat plates in a standard Instron testing machine (see Figure 1). Several cylinders were deflected to the point of failure, which usually occurred at about three inches deflection. Dynamic fatigue testing was done in a punch press. One of the cylinders showed no visible deterioration nor load/deflection change after 1,000,000 cycles from zero to one inch deflection on the diameter. This behavior was interpreted as sufficient indication that the GFRP material could probably withstand the dynamic fatigue loadings found in an operational tire.

The feasibility of winding the required toroid was then investigated. There were no machines on the market immediately suitable for this specific purpose. A Pierce tire wrapping machine, modified extensively to Owens-Corning specifications, was purchased for use as a toroid winder. During initial winding trials this machine was further modified by Owens-Corning.

Before winding the toroids, a suitable package of glass fiber roving - epoxy prepreg had to be developed. A special end-cap spool was dimensioned to permit creeling of five packages on the winder shuttle. A method was developed for placing wet prepreg roving on these spools in a near-parallel wind pattern so that the roving could be unwound without difficulty. Also, a method was devised for making hollow toroid sand mandrels that were readily disintegratable in water.

Several complete GFRP toroids were wound and cured. Although the winding pattern was not precise enough to yield a toroid suitable for testing, the results did indicate the existence of a high probability of success for the winding process.

One GFRP toroid was completely covered with sidewall rubber cut from thin sheets, wound with nylon tape, and vulcanized. A Bandag tread was then bonded to the rubber.

A GFRP split wheel was designed and a prototype was produced using a wood mold. This part was made for demonstration only; no attempt was made to fabricate a testable article. The in-house produced model GFRP tire and wheel assembly is shown in Figure 2.

The contractual program described in this report involved further development and fabrication of GFRP tires suitable for dynamic testing by USATACOM.

## II. PROGRAM OBJECT

The object of the program was to provide adequate data on which to base a judgment of the probability of success in producing a satisfactory GFRP pressureless tire by the filament winding method.

## III. SUMMARY

A process was developed to produce a preliminary model of a workable GFRP tire (nominal 7.00 - 16 size). The major developmental features of this process were: (1) a water disintegratable sand/polyvinyl alcohol (PVA) mandrel; (2) 30 percent resin roving prepreg with consistent, wide band width; (3) techniques for winding the roving on the mandrel; (4) retention of 30 percent resin in the carcass; (5) slitting the carcass; (6) applying rubber; and (7) laying up a GFRP rim.

One glass fabric tape and five roving carcasses were wound. The tape wound carcass was equipped with strain gages and tested under static load; extensive static load testing was done also on the first roving wound carcass. The latter was slit radially to various depths with different slat widths, and was tested with and without rubber. The remaining four carcasses were tested dynamically on the indoor wheel at TACOM.

It was found that an as-wound, monolithic GFRP carcass is too stiff to approach the load/deflection characteristics of a pneumatic tire. High stresses occur in the carcass at small deflection and a correspondingly small footprint area is produced. However, by slitting the GFRP carcass radially, the load/deflection properties and the footprint area of a standard 7.00 - 16 pneumatic tire were approximated. These GFRP slit-carcass tires with rubber, tire cord, and/or GFRP on the tread area were run on the indoor wheel at TACOM at axle loads up to 850 pounds (equivalent to 1000 pounds on flat surface) and speeds up to 40 mph. The last carcass made for this program (Tire #4) ran for 239 miles at 850 pounds load. Most of this run was made at 40 mph. The GFRP carcass was still completely intact when the rubber tread and the GFRP rim debonded. It appears probable that this carcass design could have provided a significantly longer life if better GFRP rim and tread rubber bonds had been available.

The feasibility of a GFRP nonpneumatic vehicle tire has been demonstrated. There exists a high probability that a serviceable, low vulnerability, pressureless GFRP tire can be successfully developed.

## IV. CONCLUSIONS

The feasibility of a GFRP nonpneumatic vehicle tire has been demonstrated. There exists a high probability that a serviceable, low vulnerability, pressureless, filament wound GFRP tire can be successfully developed.

## V RECOMMENDATIONS

It is recommended that the development program be continued. Program continuation would involve:

1. Continuous upgrading of equipment, tooling, and processes to enhance tire quality and reduce unit cost.

2. Evaluation of various tire designs by experimentally locating points of high strain magnitude and design changes to alleviate strain concentration.

3. Development of stronger bonds between rim and carcass and between tread and carcass to enhance immediately the test life of the tire at nominal loads and speeds.

4. Evaluation of tire performance on vehicle and implementation of indicated design changes.

5. Evaluation of tire resistance to various forms of abuse and implementation of indicated design changes. Abuse evaluation would include overload conditions, and various types and degrees of tire damage.

## VI. PROGRAM DISCUSSION

### A. Stress Analysis

#### 1. Theory

A study of the membrane shell theory showed that it cannot be used to design a GFRP tire because of the difficulty in specifying the applied and reactive loads. The theory is discussed in Appendix I.

#### 2. Trial

A carcass was wound using five plies of two inch wide HG 64* glass fabric tape. The toroid had a seven inch diameter circular cross-section, a 16 inch ID, and 28 inch OD. This carcass was to be loaded to determine stress-strain characteristics at various points in the tire.

The tape had been vacuum impregnated previously on five spools with ERL 2256, ZZL 0820 epoxy resin. The tape was wound on a sand mandrel with 1 3/4 inch lead on the OD. Each spool contained just enough material to go around the mandrel once. The shuttle was actually turned slowly by hand in hopes that this might let air work its way out of the laminate. The layup was then overwrapped with two inch wide polyvinyl alcohol (PVA) and heat cured.

After complete cure of the carcass, a 3/8 inch hole was drilled along the ID and a 3/16 inch hole drilled along the OD on the opposite side. The OD and ID wall thicknesses were about 1/16 inch and would not hold water. The sand mandrel was not readily disintegratable in water. Subsequent experiments showed that the sand/PVA mix has a tendency to become partially insoluble after four hours at 300°F. Accordingly, in subsequent experiments the sand mandrel was washed out after two hours cure at 185°F.

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*Hess Goldsmith woven fabric tape

A circle of 3/4 inch plywood was laid in the carcass ID and bonded in with glass fabric - epoxy to form a rim. Holes were drilled in the plywood so the wheel and carcass could be mounted on an axle for static test.

Figure 3 shows the carcass in the test machine. Four strain gages were attached in the radial direction and four in the circumferential direction. Vertical and horizontal sidewall deflections were measured at five points on a radial line. Figure 4 shows the load and total deflection curves for three separate loadings at one radial location, and one loading at a radial location 90° from the first. Figure 5 shows plots of the vertical and horizontal deflection readings.

In spite of the relatively low quality and resultant low modulus of the laminate, the structure was too stiff. This resulted in a very small sidewall deflection compared to the deflection in the footprint area. Laminate failure apparently occurred in the radial direction in the footprint area.

The largest strain recorded by the strain gages was 1200 micro-inches. Using an estimated modulus of 3,000,000 psi, the maximum stress computed from the strain gage readings was only about 3600 psi. Of course, the stresses in the footprint area were probably much greater, but we do not know how much greater.

It appears that the tire shape, low laminate quality, relatively low circumferential strength, and possibly other factors, contributed to failure at loads that are about half of what a conventional vehicle tire will have to withstand in service.

The footprint area is shown in Figure 6. Being less than ten square inches, it is probably too small for practical use.

The experience of making and testing this fabric wound carcass indicated that:

1. A satisfactory fabric wound GFRP carcass would be more difficult to make than a satisfactory roving wound carcass.

2. Satisfactory load/deflection and footprint characteristics probably cannot be demonstrated by a GFRP continuous carcass.

Accordingly, we resumed development of a process to wind a satisfactory GFRP carcass with roving, and commenced investigation of the effects of carcass slitting on load/deflection and footprint characteristics.

## B. Winder and Process Refinement

The original concept of winding a carcass involved use of a substantial angle of wind which would require several revolutions of the mandrel to obtain coverage. In trials it was determined that the winding apparatus was not compatible with this concept. The mandrel would either precess or recess through successive revolutions, sometimes gradually, sometimes abruptly, and usually not at all until after several revolutions. A great deal of unsuccessful work was done trying to solve this problem. Consequently, all carcasses subsequently made in this program were wound at a very small angle in order to obtain complete mandrel coverage with one revolution of the mandrel.

Following are some of the things that were tried to solve the winding precision problem. All this work was done using five spools of roving on the winder at a time. Using 20 or 30 end roving, each roving band width was about 1/8 inch.

(1) The entire winder was investigated on several occasions for alignment, play, dimensional accuracy, and possibility of slippage in all drive elements. No serious defects were noticed.

(2) A Cleveland Speed Variator was tried in place of a Graham variable speed transmission.

(3) To eliminate mandrel slippage for analysis purposes, the Graham transmission was replaced with a gear box, and a chain was embedded in the periphery of the mandrel so that the mandrel could be positively driven by a sprocket instead of the friction drive wheels. The results of this were inconclusive.

(4) All chains were eliminated from the winder drive system. The mandrel drive drum was linked directly to the shuttle

by spur gears and through the Graham variable speed transmission. This appeared to give a slight but insufficient improvement. This system was retained without change throughout the remainder of the program. One drive drum is tied to the shuttle through only gears and the Graham transmission. The second drive drum is linked to the first drive drum by one chain.

(5) The concave OD surfaces of the drive drums were machined flat.

(6) A much larger angle of wind could be used if a tape much wider than the 1/8 inch wide roving could be used. The nominal lap of the tape might then be made larger than any random variations with successive revolutions of the mandrel. Doing this became quite complicated because the tape supply packages had to be positioned at an empirically determined angle with reference to the mandrel. This angle had to be reversed when the windings were reversed, resulting in a very tight space problem for positioning the packages when the mandrel was rotating counter-clockwise.

Winding with 1/2 inch and 1 inch masking tape, and glass fabric tape as readily available process trial materials, looked promising. However, winding with unidirectional glass fiber tape was unsatisfactory. In general, due to the geometry of the mandrel and the fact that a unidirectional glass tape has no stretch, it was found that tape as narrow as 1/2 inch would not lie flat on the mandrel at the middle of the sidewall. Glass fabric tape was not considered seriously because it is inherently expensive, and because we do not know of a practical process for winding a high quality, void-free laminate using woven material.

It was decided that the winder precision problem should be deferred while going ahead with winding a carcass using the best band width and angle obtainable. However, using 30 end, S-904 roving, it was found that:

(1) The band width was too variable and too narrow, resulting in a tendency to gap, even with a closed circumferential wind.

(2) The band was not flat, resulting in a severe corduroy surface which prohibited making a satisfactory carcass.

Input material into the prepreg operation was switched from 30 end roving to 30 ends from forming cakes, which decreased the variability of the band width significantly. Also, replacing the narrow guide eye on the winder with a 3/4 inch radius guide and applying the band under a spring loaded roller running on the mandrel, widened and flattened the band a great deal. The spring-loaded roller design took considerable time to develop. The roller assemblies have to fit in a relatively congested space on the shuttle, and five assemblies are required to accommodate five spools. The first design utilized a torsion spring. This gave a satisfactory wind on the wood pattern, but not on the sand mandrel. Evidently the springs were not powerful enough, and there was a variation in strength between springs. The entire assembly was redesigned to use a compression spring which provided a larger and easily adjustable force. These rollers were so successful that the original narrow guide eyes could be used.

C. Carcass #1

Throughout this program the prepreg roving was made from 30 ends of S-904 directly from forming cakes. The resin system was an epoxy ERL-2256, ZZL-0820. The cross-sectional shape used for all of the carcasses in this program is shown in Figure 7. It is the original seven inch diameter circular section with two inches removed from the outside diameter of the mandrel (one inch from cross section). A wood pattern and plastic sand mold were made for an alternate shape shown in Figure 8, but no carcasses were wound to this shape.

Carcass #1 was made using the general process detailed in Appendix II. A plywood and GFRP rim was molded onto the carcass. Carcass thickness on the OD measured about 0. 083 inch, and resin content was about 17%. Three inch deep radial slits were cut in one section of the carcass and four inch slits in another section. The slits were one inch apart on the OD.

The carcass mounted on an axle was placed in a Baldwin testing machine as shown in Figure 9. Three sections of the carcass were tested; the center of each of the two slit sections, and a position in the unslit section. The end point of each test was to be either 1000 pounds load or one inch deflection. The results are shown in the load-deflection curves on Figure 10. Footprint areas at highest loads are shown in Figure 11.

These tests showed that the unslit section was too stiff for practical use as a tire. This carcass laminate section began to fail at less than 1/4 inch deflection and less than 600 pounds. The footprint area was less than nine square inches.

The slit sections looked much more promising. Both sections sustained 1000 pounds load without failure, and deflections approached the target of one inch. Footprint areas were over 30 square inches at 1000 pounds.

A third section of Carcass #1 was slit one inch (slat width on OD) by five inches (depth from OD). This section was then loaded to 2000 pounds without failure. The three inch and four inch sections that had previously been loaded to 1000 pounds were loaded to failure. The four inch section exhibited an ultimate strength of only 1270 pounds, while the three inch section went to 1620 pounds. Ultimate in these cases is merely a sudden drop of several hundred pounds in load, but is not necessarily catastrophic. These load/deflection curves, along with those for the unslit section, are shown in Figure 12. The footprints for the three slit sections at ultimate are shown in Figure 13.

Half the remaining section of Carcass #1 was slit one inch by five inches, and the other half 3/4 inch by five inches. One ply of .070 inch raw rubber was laid on the entire surface, wrapped with cure tape, and vulcanized. Rubber was allowed to flow into the slits. One layer of .070 inch raw rubber was then applied to the tread area, and covered with one ply of glass tire cord reinforced rubber with the cord oriented in the circumferential direction. This was then wrapped with cure tape and vulcanized. Bandag tread was then bonded to the tread area.

A GFRP split wheel was then molded directly on the tire. The center portion on one half contained six ply of 182 fabric, and the portion in contact with the tire contained three ply of 182 fabric.*

The one inch by five inch slit section was loaded twice to 1500 pounds and twice to 2000 pounds. The 3/4 inch by five inch slit section was loaded once to 1160 pounds and twice to 1500 pounds. The

* this construction is called "three ply plus three ply."

load/deflection curves for each loading of the two sections are shown in Figure 14, 15 and 16. The curves show considerable hysteresis and apparent mechanical adjusting for the first two loadings. The curves then smooth out and settle down on the third and fourth loadings.

The load/deflection curves for the four successive loadings of the one inch by five inch slit section are shown in Figure 17 and the curves for the three successive loadings at the 3/4 inch by five inch section are shown in Figure 18. In both sections load relaxation appeared to approach zero after the third loading. There appears to be no significant difference in the load/deflection curves of the one inch slits compared to the 3/4 inch slits. Comparison of the load/deflection of the bare carcass one inch by five inch slits indicates that the rubber does not change the curve significantly. The one inch by five inch slit section is compared with the load/deflection curve for a 7.00 - 16, 6 PR pneumatic tire (25 psi) in Figure 19. These curves are amazingly close considering that this was a first try of an empirical experiment. Figure 20 shows the one inch by five inch slit section under 2000 pound load. The footprint area at maximum last loadings on the rubber covered sections are shown in Figure 21.

D. Tire #1

It was decided that an efficient approach to the delivery of five tires would be to make and test one tire at a time with possible modification between each one. This procedure would be followed until such time as test results might indicate that several tires made exactly the same would be desired. The favorable load/deflection results of the slit portions of Carcass #1 dictated that Tire #1 should be a similar construction.

The carcass for Tire #1 was wound 10 ply using essentially the same process as was used for Carcass #1. The carcass was slit one inch by five inches around 360°; the last slit was less than one inch wide. About 1/8 inch of rubber was vulcanized on the entire carcass, with two ply of glass cord reinforced rubber sheet on the tread area. A complete Bandag precured tread was bonded to the carcass. A GFRP rim was laid up on the tire. The rim was made in two halves and not bonded to the tire.

The slit carcass weighed eleven pounds; it is shown in Figure 22. Resin content of the carcass, measured by burn-off of several slats, was about 17%.

Tire #1 was loaded a number of times up to 1500 pounds on a flat surface (Figure 23). The load-deflection curve was found to be essentially the same as that for Carcass #1. The tire deflected one inch at 1065 pounds. The tire was then loaded a number of times on a surface with the same radius of curvature as the TACOM dynamometer wheel (67.23 inches). A one inch deflection was measured at 878 pounds.

The tire was mounted on the TACOM Dynamometer wheel and speed was increased slowly to 20 mph under about 700 pounds. The wheel rotated in the tire which put the wheel/tire assembly out of balance. Several attempts to fasten the wheel mechanically to the tire were unsuccessful. The wheel was then bonded to the tire with epoxy.

The tire was run for a number of hours at loads up to 950 pounds (equivalent to about 1000 pounds on flat surface) and speeds up to 30 mph. Tread surface temperature was monitored with an optical pyrometer. After 59 miles of running, the tread debonded and fell off. Inspection showed that the tread had been bonded only on the edges. The tire was then statically tested and the load/deflection curve was found to be the same as it was initially. The tire without tread was put back on the dynamometer wheel and run for a short period at 850 pounds and 22 and 26 mph when several slats failed in the carcass. When the tire was cut open, it was found that every slit had propagated across the ID approximately to the slit opposite. As a result, the carcass had become a series of more or less completely separated rings. The rubber was also generally debonded from the carcass. Evidently several of the rings became completely separated from the rubber and from adjacent rings and jumped out of place because of the forces of severe bouncing. These rings were found, intact, inside the carcass. This type of carcass failure was not unexpected because the very low wind angle provided little more than the strength of the resin in the radial direction.

Tire #1 performance on the indoor wheel is summarized below:

| | Load (pounds) | Speed (mph) | Time ( min. ) | Miles | Cumulative Miles |
|---|---|---|---|---|---|
| (1) | 700 | 0 - 20 | 7 | 1 | 1 |
| (2) | 625 | 10 | 12 | 2 | 3 |
| (3) | 625 | 20 | 18 | 6 | 9 |
| | Drilled and pinned rim to tire | | | | |
| (4) | 650 | 20 | 9 | 3 | 12 |
| | Bonded rim to tire with epoxy | | | | |
| (5) | 650 | 10 | 6 | 1 | 13 |
| (6) | 850 | 19 | 75 | 24 | 37 |
| (7) | 850 | 24 | 36 | 14 | 51 |
| (8) | 850 | 30 | 15 | 8 | 59 |
| | Tread tore off | | | | |
| (9) | 850 | 22 | 20 | 73 | 132 |
| (10) | 850 | 26 | 52 | 23 | 155 |

## E. Tire #2

Due to delays experienced in having Tire #1 cut open, Tire #2 was made before the mode of failure of Tire #1 was known. When Tire #1 was cut open, it was obvious that the changes incorporated in Tire #2 would have no significant beneficial effect on failure by extension of the slits across the ID which was the failure mode of Tire #1. Indeed, after a relatively short time at low speeds Tire #2 did fail in this way.

Tire #2 was made different from Tire #1 in the following respects:

(1) The prepreg roving was made and the carcass was wound and gelled at a lower temperature in an attempt to get a higher resin content.

(2) The slits were equally spaced.

(3) The tire had cord and rubber on the OD (no tread) and one layer of 1/16 inch rubber on the ID under the rim. The carcass could be visually inspected for failure during the test.

Target composite resin content was 30% by weight. A considerable amount of development work was done to increase the resin content in a spool of prepreg roving, and subsequently in a carcass to 30%. Working only with the standard resin system (ERL 2256, ZZL 0820),

it was found that almost 30% resin could be obtained in the spool and retained in the carcass by processing at about 70°F until the resin had gelled. Resin content was measured as almost constant from the inside of the spool to the outside. Use of an oblong die instead of a circular die to scrape off excess resin increased the resin content and provided a wider, flatter, and more consistent prepreg roving band. A carcass section was simulated by winding from prepreg spools and curing on a 6 3/8 inch diameter cylindrical mandrel.

The tread area of Tire #2 was covered with 1/8 inch rubber, one circumferential winding of glass tire cord, 1/16 inch rubber stitched on, a second winding of glass tire cord, and a final layer of 1/16 inch rubber stitched on. The tire was wrapped with PVA tape and all rubber on the OD and ID was vulcanized simultaneously.

The drill jig center guide hole in the rim was located using a fairly imprecise pattern. As a result, the lug holes were about 1/8 inch away from the true center of the tire OD. The procedure for locating the center of the tire was improved on subsequent tires.

Tire #2 was loaded statically twice to 1000 pounds, then to 1500 pounds, then again to 1000 pounds. Very slight noises could be heard as the load approached 1500 pounds. Deflection was 0.7 inches at 1000 pounds (Tire #1 was very close to one inch at 1000 pounds). After the tire had been run to failure, deflection was 0.9 inches at 1000 pounds. This tire was not dissected for a determination of the resin content and wall thickness. However, fabrication procedures were designed to yield a laminate resin content greater than Tire #1. This would increase the wall thickness. Assuming it did, the thicker wall of Tire #2 is probably the reason that Tire #2 was stiffer than Tire #1.

Tire #2 performance on the indoor wheel is summarized below:

| | Load (pounds) | Speed (mph) | Time (min.) | Miles | Cumulative Miles |
|---|---|---|---|---|---|
| (1) | 600 | 5 | 120 | 10 | 10 |
| (2) | 600 | 10 | 330 | 55 | 65 |
| | Failed across ID. | | | | |
| (3) | 200 | 30 | 1 | (bounced) | |
| (4) | 300 | 35 | 1 | (bounced) | |
| (5) | 300 | 10 | 960 | 160 | 225 |

No failure had been detected after (1) above. The tire was not watched during (2), but the chart showed that bumping had started after five hours. Visual inspection showed that the carcass had failed, as expected, by the propagation of the slits across the ID. No other failure was evident. The tire was then run for 16 hours at low speed and low load (5) to determine if the tire would begin to fail in other areas. There was no further visible deterioration at the end of the test.

Figure 24 shows Tire #2 loaded on the indoor wheel at the completion of above testing. It can be seen that the ends of the slits come to about 1/2 inch from the edge of the rim. Dust from carcass laminate failure across the ID can be seen around the edge of rim.

F. Tire #3

1. Construction

Tire #3 was made using an eight ply carcass that had not been completed some weeks earlier because of a lathe failure. The carcass was wound and gelled somewhere between 85 - 100°F (summer ambient), so the resin content, 18 percent, was between that of Tires #1 and #2. Carcass thickness on the OD was .067 inches. Slits were one inch by five inches, and the last slat was narrower than the rest.

One layer of 1/16 inch by six inch rubber was wrapped on the tread area. Three pieces of 1/4 inch wide rubber were wrapped on circumferentially and one inch apart. Four one-inch wide GFRP belts (3-ply of HG 64) were laid up between the 1/4 inch rubber strips. Finally, one layer of 1/8 inch by six inch rubber was wrapped over the tread area. The entire lay up was then wrapped with PVA tape and cured for two hours at 185° F, plus two hours at 300°F.

The GFRP rim was laid up directly on the carcass. Each half consisted of seven ply of 182 fabric in the center and three ply on the carcass and out to the slits. No release agent was used between the two halves. Using a compass, the center guide hole was laid out with reference to the tire OD. Lug holes and hub hole were then machined in the rim, and the tire was statically balanced.

2. Static Test

To determine the effect of the GFRP belts on load/deflection, the unbelted carcass was loaded on a temporary split wheel. The plan was to deflect to one inch and record the load. Unfortunately, at about 7/8 inch deflection and 545 pounds, the carcass failed suddenly (and with a loud noise) along the fibers, across the ID, at the point of load. It was expected that this failure would have no significant effect on the strength of the completed tire because the bonded-on rim would hold the carcass together at the point of failure.

The completed tire was statically loaded at TACOM. It was first loaded at a point about a third of the way around from the point that had previously failed. The load was 865 pounds at 1 inch deflection. Apparently the GFRP belts stiffened the carcass significantly. Some small cracking noises were heard, but were not considered significant. The tire was then loaded at the point of previous failure to 400 pounds and 5/8 inch deflection. The two load/deflection curves appeared to be identical.

After the tire had been run on the wheel for 30 minutes at 10 mph and 400 pounds, and for 30 minutes at 10 mph and 500 pounds, it was removed from the wheel and again loaded statically at the same two points. Both curves (load/deflection) were essentially identical to those obtained on the virgin tire. Deflection was about 3/8 inch at 500 pounds.

3. Wheel Test

The following table presents the sequence of Tire #3 tests on the indoor wheel. The tire was stopped and inspected after each 30 minute run. It should be noted that the equivalent flat plate loads would be about 15 - 20% higher than the curved plate loads listed below.

| | Load (pounds) | Speed (mph) | Time (min.) | Miles | Cumulative Miles |
|---|---|---|---|---|---|
| (1) | 400 | 10 | 30 | 5 | 5 |
| (2) | 500 | 10 | 30 | 5 | 10 |
| (3) | 500 | 15 | 30 | 7.5 | 17.5 |
| (4) | 600 | 15 | 30 | 7.5 | 25 |
| (5) | 600 | 20 | 30 | 10 | 35 |
| | Failure noted at this point | | | | |
| (6) | 600 | 36 | Bounced and kicked out machine | | |
| (7) | 600 | 50+ | 2 | 2 | 37 |
| (8) | 700 | 20 | 30 | 20 | 57 |
| (9) | 700 | 25 | Could not get tire to run smoothly. Kicked out machine several times. | | |

The inside of the carcass could be inspected by placing a light against the slits and by looking through the slits. Also, the rim and carcass were both quite translucent which aided visual inspection.

The rubber was getting softer on each inspection and was chunking out. It is possible that a good rubber cure was not obtained because of the presence of epoxy, and the curing conditions used. This problem was arrested by wrapping a fabric reinforced tape over the tread area. The tape began to split almost immediately, but stayed on for the duration of the test.

While running up to speed on (5) (see above table), the tire bounced fairly heavily at about 18 mph but smoothed out nicely at 20 mph. The first failure noticed, between (5) and (6), consisted of a radial crack in mid-slat which extended down for about one to two inches from the edge of the rubber. Such cracks were noted in only five or six slats on each side. This is the same type of failure that had previously occurred on the ID. It was apparent that by bonding the rim directly to the carcass the second highest point of interfiber stress was in the carcass where the sidewall blends into the tread area.

Since the tire was still 99% intact, it was decided to determine how the tire would perform at relatively high speed. At 600 pounds load the tire was run up to 36 mph where it bounced and turned off the wheel. Load was reapplied and the speed taken up quickly through 37 mph when it smoothed out and ran smoothly up to over 50 mph (maximum speed for this wheel). It was allowed to run for a couple of minutes and then unloaded.

Inspection after (8) revealed that more slats had cracked and that previous cracks extended down the side wall. Some, if not all, of these cracks ran all the way across the slat under the tread. A dark line had appeared for about one inch down under the rim from the end of the slits. These were probably cracks in the carcass.

The conditions shown in (9) could not be attained because the tire would not run smoothly between 20 and 30 mph. Inspection showed that slats had debonded from the rubber in several places, and at one point two adjacent slats were completely debonded. The debonded areas were soft spots and this is probably the reason the tire would not run smoothly. At this time, most slats showed some evidence of failure, and some slats had several cracks, a few extending down about three inches. However, some slats were apparently still completely intact. The rim had failed radially on one side only, and in about five places. At one place the three ply rim exhibited failure completely through its thickness and for its full radial length. The rim was also debonded from the carcass about four inches on each side of that failure.

G. Tire #4

1. Construction

Two new construction details were tried on the carcass for Tire #4.

The first was an attempt to include an epoxy bonded surface mat (M-514, Treatment #246) in the carcass laminate to provide some strength perpendicular to the general direction of the wound roving. This mat material is not ordinarily used in structural GFRP laminates. It was therefore decided to determine, using small specimens, suitability of the mat to the winding process and the wet and dry interlaminar shear strength of a wound laminate containing this mat. Four plies of this mat were laminated into a circ wound cylinder. The cylinder was tested and found to be surprisingly strong in the direction perpendicular to the circ windings. In addition, three plies of this mat were laminated into a standard glass fabric reinforced flat laminate. This laminate was tested for interlaminar shear strength dry and after 72 hours in 190°F water. All failures were between fabric plies initiating at

the bottom of the notch. It was concluded that the mat provided sufficient dry and wet shear strength. Other advantages of this mat are that it can be wound as a tape, wets through quickly, is very thin, and holds a high resin content. Several trial windings on the wood mandrel revealed no problems. Unfortunately, in trying to apply this mat in the carcass for Tire #4, the drive wheels wrinkled the mat and severed it where the carcass contacted the sandpaper-covered drive wheels. These processing problems could not be readily solved, so the mat was unwound from the carcass and style HG 64 glass fabric tape wound on in its place. The fabric tape processed reasonably well. Two plies of HG 64 were laminated into the carcass; one after roving ply number 4, and one after ply number 6.

The second new construction detail was the incorporation of a GFRP circ belt on the OD of the carcass. The most convenient way to obtain this feature was to slit the carcass from the sides, thereby leaving a portion of the OD and ID intact all the way around. The largest part of the strength in this belt would come from the two ply of HG 64 fabric.

The resin content was 26 percent; this approached the target of 30 percent and was attained by gelling at close to room temperature. Carcass thickness on the OD was .129 inch.

A carbide grit bandsaw is the most practical tool for the slitting operation. Slitting from the sides required a large or special geometry bandsaw. A "roll-in" cut-off bandsaw was found to be suitable. A jig was made to hold a rotary index table which, in turn, held the carcass in the vertical position. The slits were cut two inches deep from each side leaving three inches unslit on both the OD and ID. The slits were made at exactly four degree radial intervals.

At this point in the construction of the tire, the carcass was mounted on a temporary split wheel and axle and loaded to 750 pounds; this gave about 7/16 inch deflection. Since this was considered too stiff compared to a target of one inch at 1000 pounds, it was decided to slit 1/2 inch deeper on each side on the OD (leaving a two inch "belt") in an attempt to reduce stiffness. This was done but did not result in any change in deflection at 750 pounds.

One layer of unreinforced 1/8 inch rubber was bonded on the tread area. A four ply plus four ply GFRP rim was laid up and bonded directly to the carcass out to the ends of the slits.

Tire #4 (tire, rim and balancing bolts) weighed 22.8 pounds. Runout on the OD was close to zero most of the way around, with about a 1/16 inch bump (probably air in the rubber) at one point.

Figure 25 shows the construction of Tire #4. Figure 26 shows the tire carrying the rear wheel weight of an empty 4000 pound pickup truck.

2. <u>Test of Tire #4</u>

Tire #4 was statically loaded a number of times at several points to 1000+ pounds on a flat plate and to 900+ pounds on a curved plate. Deflection on the flat plate was a little over 1/2 inch at 1000 pounds. The load on the curved plate at the same deflection was about 875 pounds (average between two curves).

Tire #4 performance on the indoor wheel is summarized below:

| | Load (pounds) | Speed (mph) | Time (min.) | Miles | Cumulative Miles |
|---|---|---|---|---|---|
| (1) | 850 | 10 | 30 | 5 | 5 |
| (2) | 850 | 15 | 30 | 7.5 | 12.5 |
| (3) | 850 | 20 | 30 | 10 | 22.5 |
| (4) | 850 | 25 | 30 | 12.5 | 35 |
| (5) | 850 | 30 | 30 | 15 | 50 |
| (6) | 850 | 40 | 10 | 7 | 57 |

The tire emitted a distinct knocking noise (seemingly once per revolution) almost from the beginning. This noise changed gradually in frequency and nature over the entire test. The tire was stopped and visually examined every 30 minutes. The only sign of failure until after (4) above was a slight amount of dust at the ends of all slits at the point of entry into the rim. Since the amount of dust was increasing, the carcass inside was examined after (4) with a light; it could be seen that the slits had propagated across the OD. The GFRP circ belt had been lost and the slats were then tied together on the OD only by the 1/8 inch thickness of unreinforced rubber.

While running at 30 mph and 40 mph, it could be seen that the slats were extending about 1/2 inch beyond normal position apparently due to centrifugal force. This put the footprint area under a tortuous loading condition at the point of contact with the drive wheel. After 10 minutes at 40 mph, the 1/8 inch unreinforced rubber serving as tread debonded, ripped, and a large section flapped off. The test was terminated at that time.

Extension of the slits across the OD was the only observable failure in the carcass. These failures probably occurred very near the start of running. About eight or ten slits had not failed across the OD (no two adjacent slits were intact). Tire #4 was considered to be successful at this point because it did not fail where previous tires had, i. e., in the laminate in the direction of the fibers.

It was obvious that this tire could be readily reworked to run again by cleaning the rubber off the OD and applying a reinforced circ belt over the carcass OD. However, all contract funds had been expended. In view of the significance of this program, Owens-Corning Fiberglas Corporation funded the rework of Tire #4 and related costs. The objective was to determine the life of the carcass at 850 pounds and 40 mph.

## H. Tire #4 Reworked

### 1. Construction

The carcass was still basically sound, and could be tested further if a circ belt could be applied on the OD to hold the slats in their proper position.

All rubber was removed, all slits were sawed and cleaned up across the OD, and the OD was sand blasted. After painting on Chemlock 205 and 220, about 1/2 inch of rubber and four plies of glass tire cord in the circ direction were built up on the OD. Extra rubber was placed at the tread sides to produce a flat running surface. PVA tape was wound on in the circ direction and plywood sideboards applied to hold the rubber in place while curing.

2. <u>Testing</u>

The tire was loaded to 1000 pounds on a flat plate at two points previously marked 180° apart. Deflection was 1/2 inch to 9/16 inch, equal to the deflection measured at the same points before the initial dynamic testing. Slight separation between rim and carcass was noted at one of these points

The reworked tire weight, with rubber and balancing bolts, was 30.5 pounds. The rubber obviously contained numerous air pockets. No static test was performed at TACOM.

Tire #4 performance on the indoor wheel is summarized below:

| | Load (pounds) | Speed (mph) | Time (min) | Miles | Cumulative Miles |
|---|---|---|---|---|---|
| (1) | 850 | 0 - 40 | 7 | 2 | 59 |
| (2) | 850 | 40 | 30 | 20 | 79 |
| (3) | 850 | 40 | 60 | 40 | 119 |
| (4) | 850 | 40 | 60 | 40 | 159 |
| (5) | 850 | 40 | 60 | 40 | 199 |
| (6) | 850 | 40 | 60 | 40 | 239 |

Rubber debond on the edges was noticed fairly early during the test. Only a small amount of dusting (laminate failure) was observed up to (6). The noise level increased steadily from (4) through (6) and the tire began to run fairly rough during (6). At the end of (6), at least one slat was completely debonded from the rubber, the rim was completely debonded from the carcass, and at least one slit had failed across the ID. No other failure in the carcass laminate was observed.

The test results of Tire #4 are extremely encouraging because they indicate that this carcass design might provide a significantly longer life once ways are found to better hold the carcass to the rim and to bond rubber on the carcas OD.

# VII. ILLUSTRATIONS

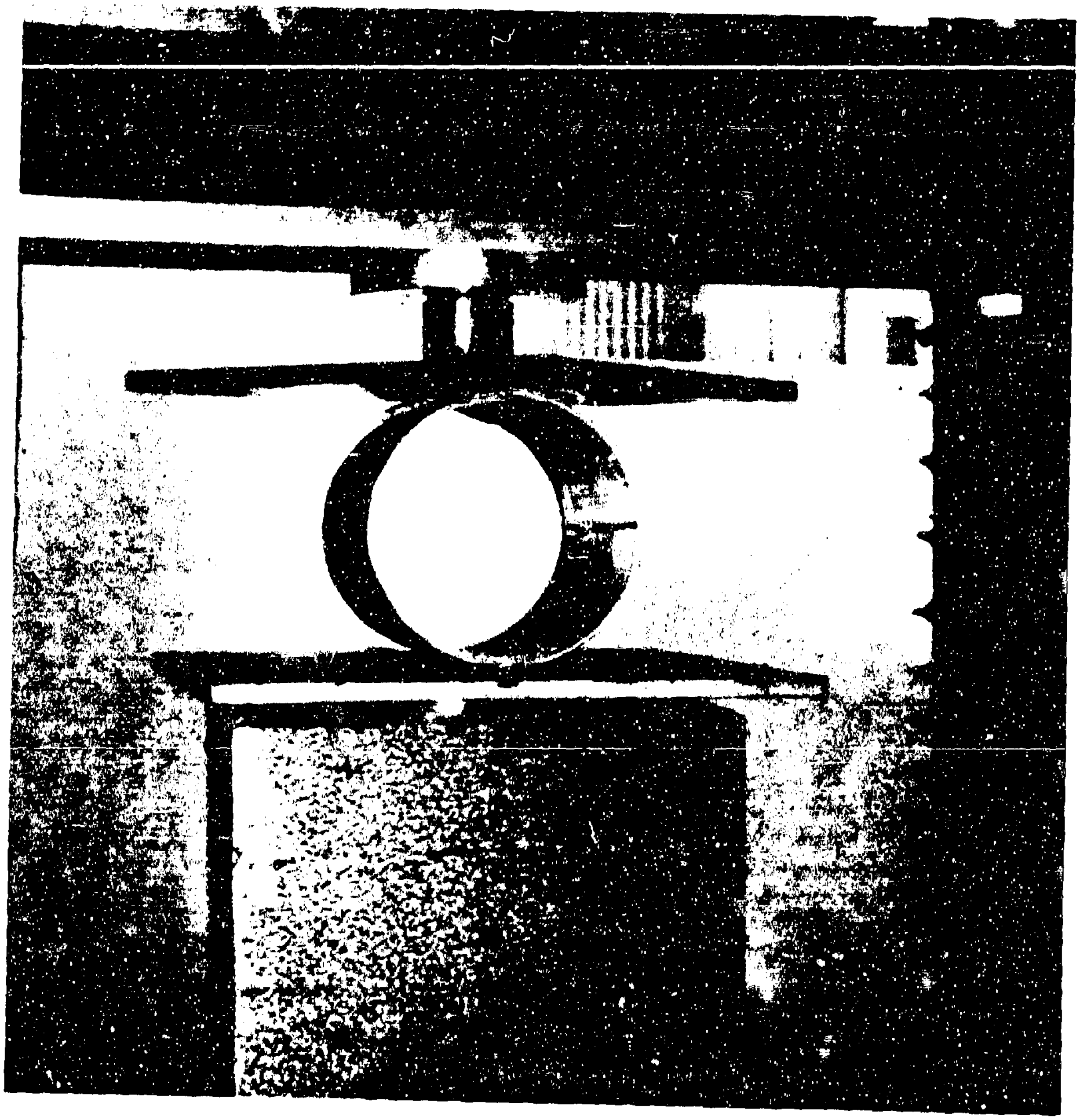
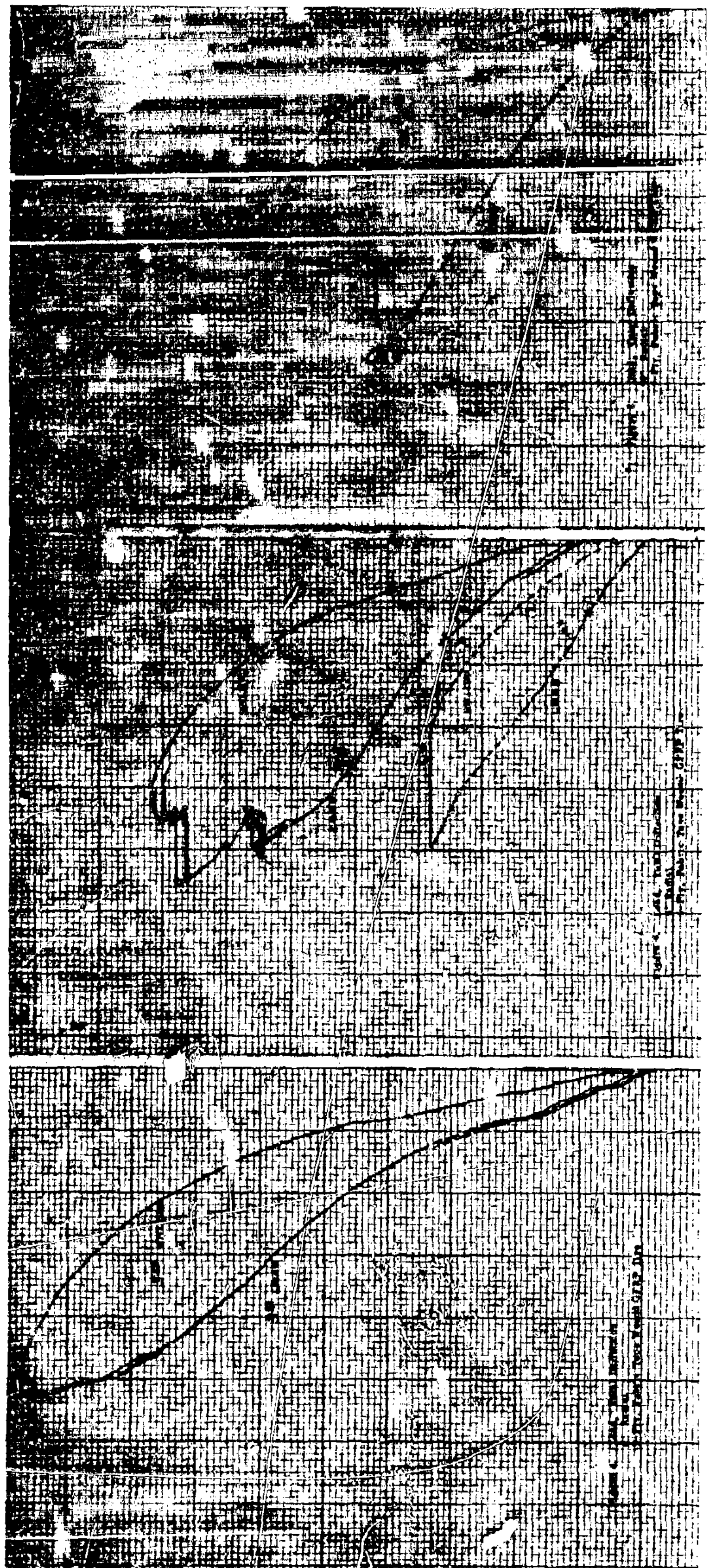


Figure 1. Filament Wound GFRP Cylinder - No Load

Figure 2. Model GFRP Tire and Wheel

Figure 3. Fabric Tape Wound Tire in Testing Machine



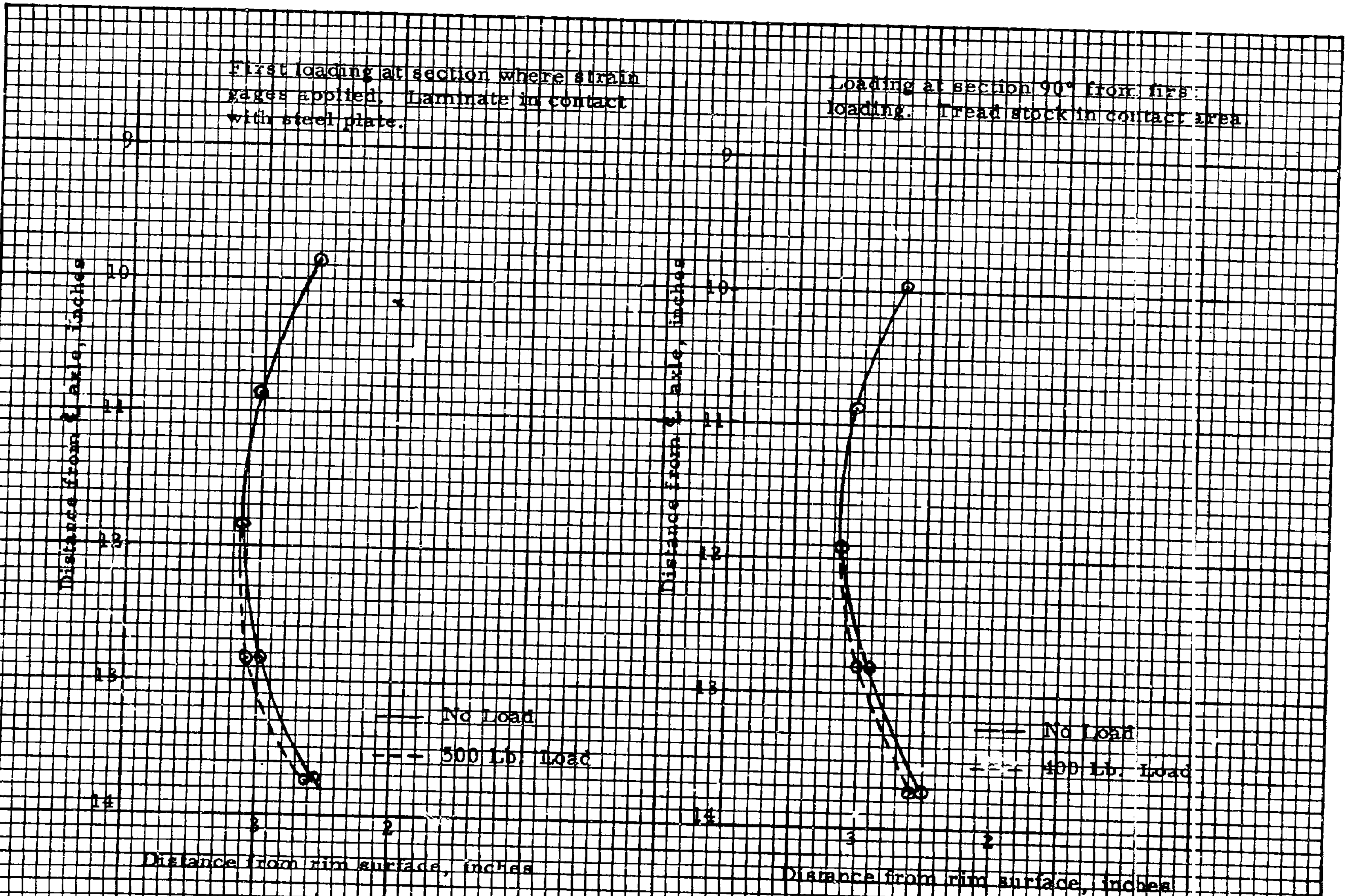



Figure 5. Fabric Tape Wound GFRP Tire Meridian Profiles

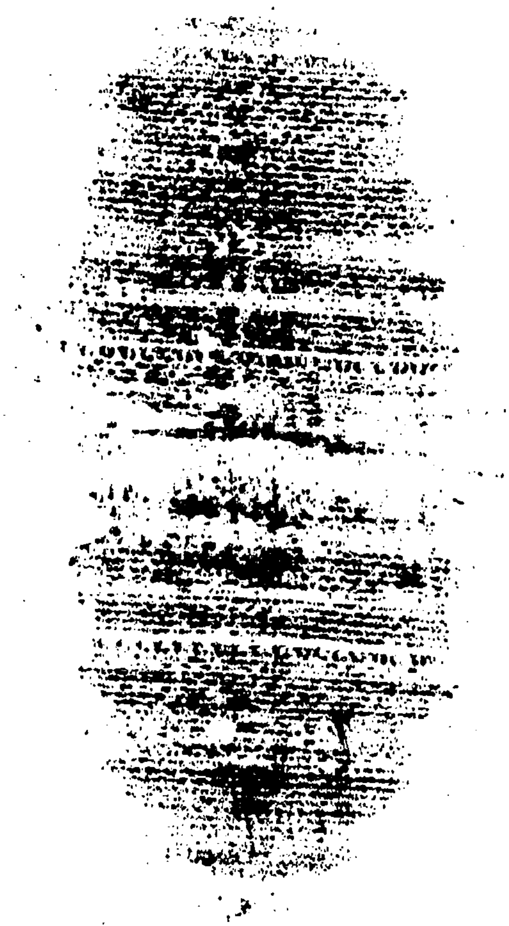


Figure 6. Footprint, Fabric-Wound GFRP Tire (400 Lb. Load)

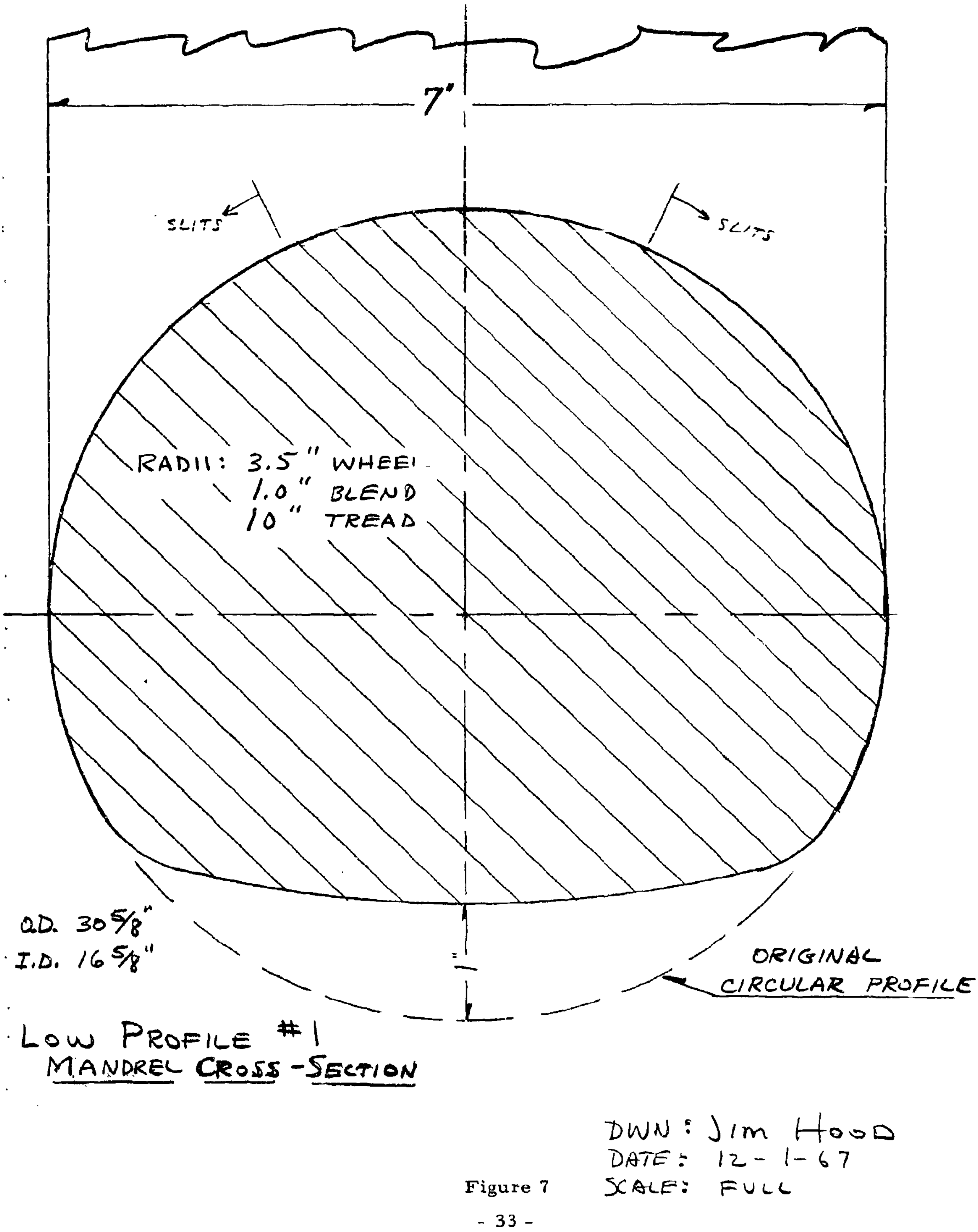
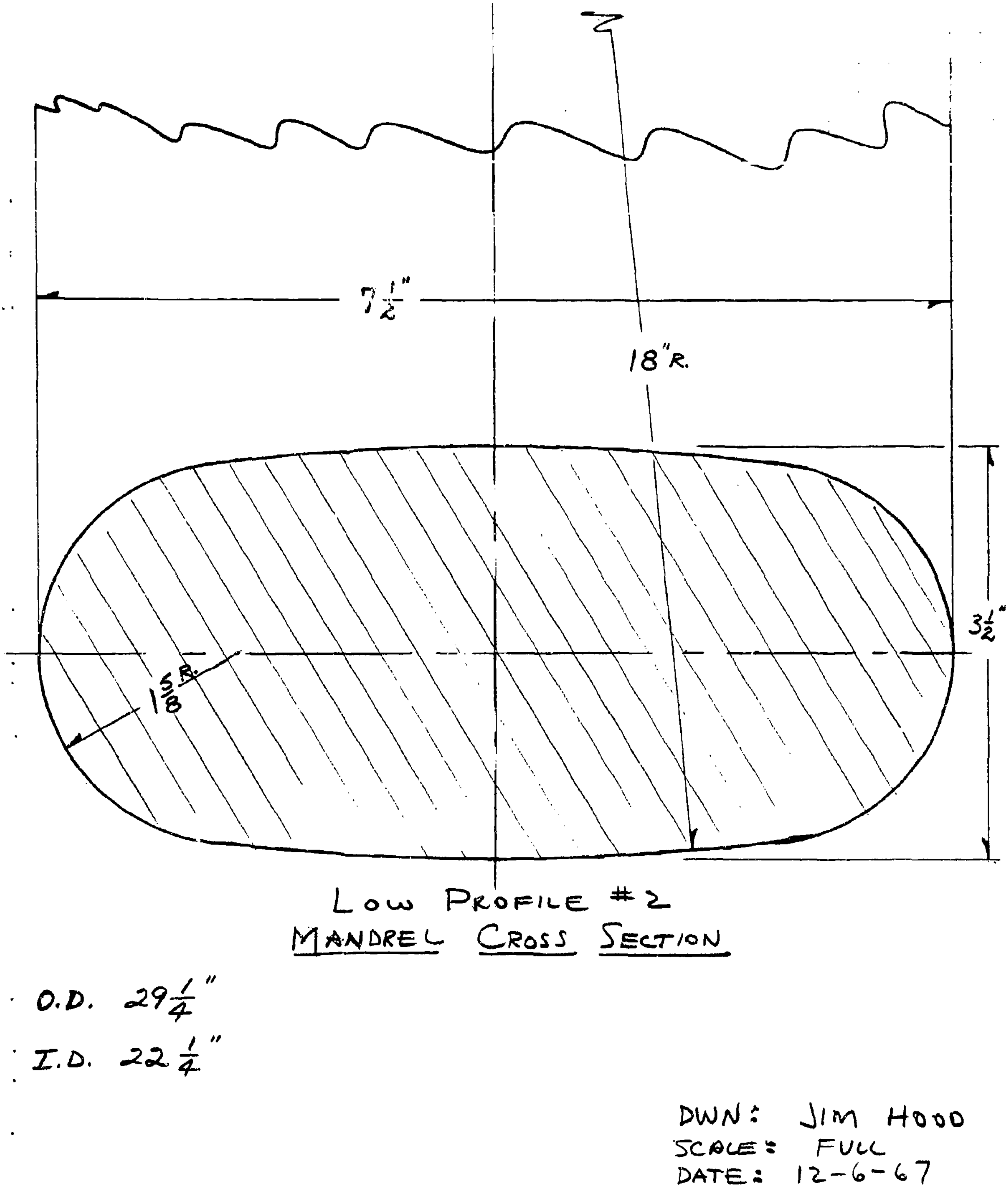

7"
SLITS
SLITS
RADII: 3.5" WHEEL
1.0" BLEND
10" TREAD
O.D. 30 5/8"
I.D. 16 5/8"
ORIGINAL CIRCULAR PROFILE
LOW PROFILE #1
MANDREL CROSS-SECTION
DWN: JIM HOOD
DATE: 12-1-67
SCALE: FULL

Figure 7



$7\frac{1}{2}$"
18" R.
$3\frac{1}{2}$"
$1\frac{5}{8}$ R.
LOW PROFILE #2
MANDREL CROSS SECTION
O.D. $29\frac{1}{4}$"
I.D. $22\frac{1}{4}$"
DWN: JIM HOOD
SCALE: FULL
DATE: 12-6-67


Figure 8

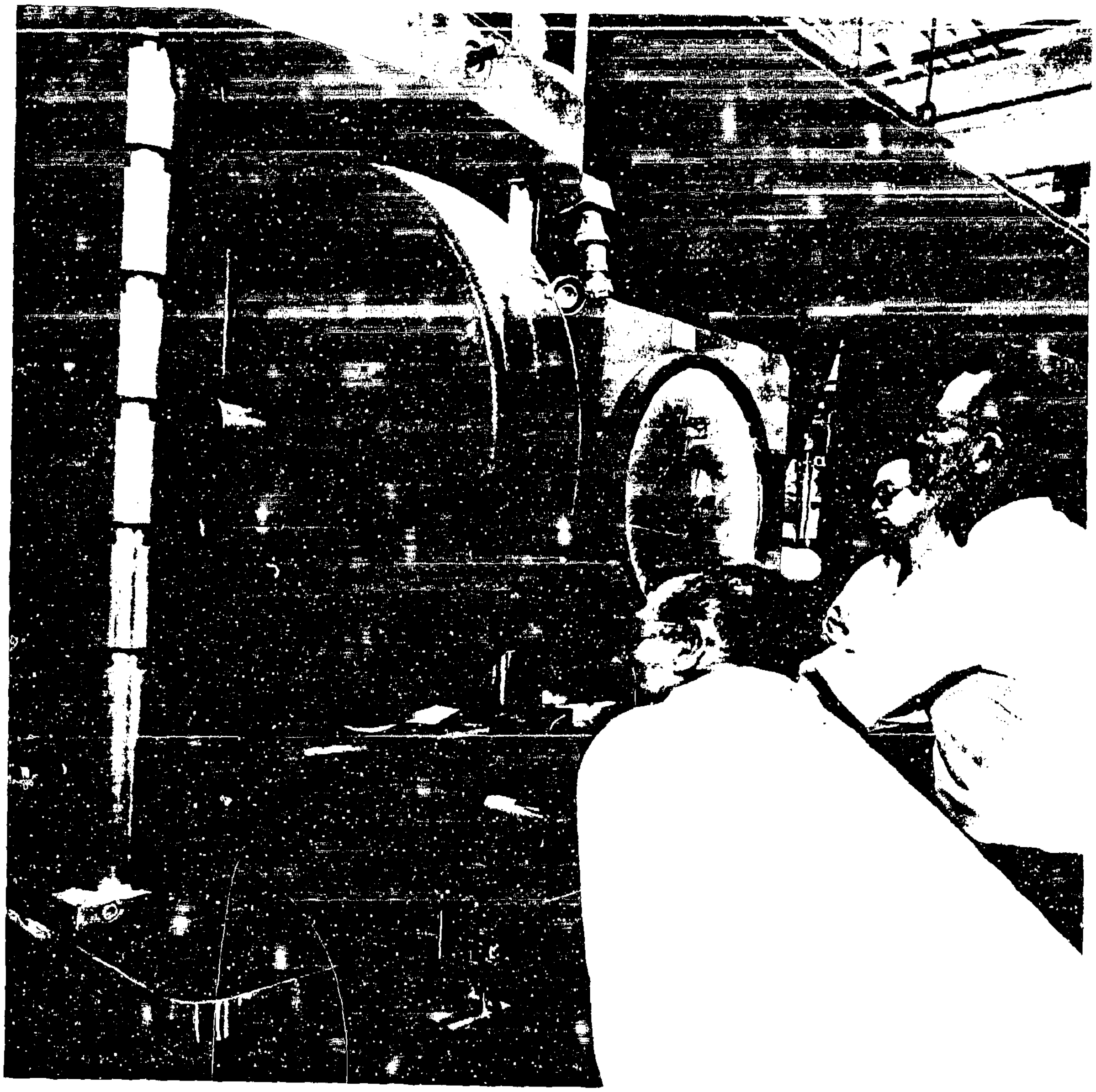


Figure 9. Carcass #1 under Static Test

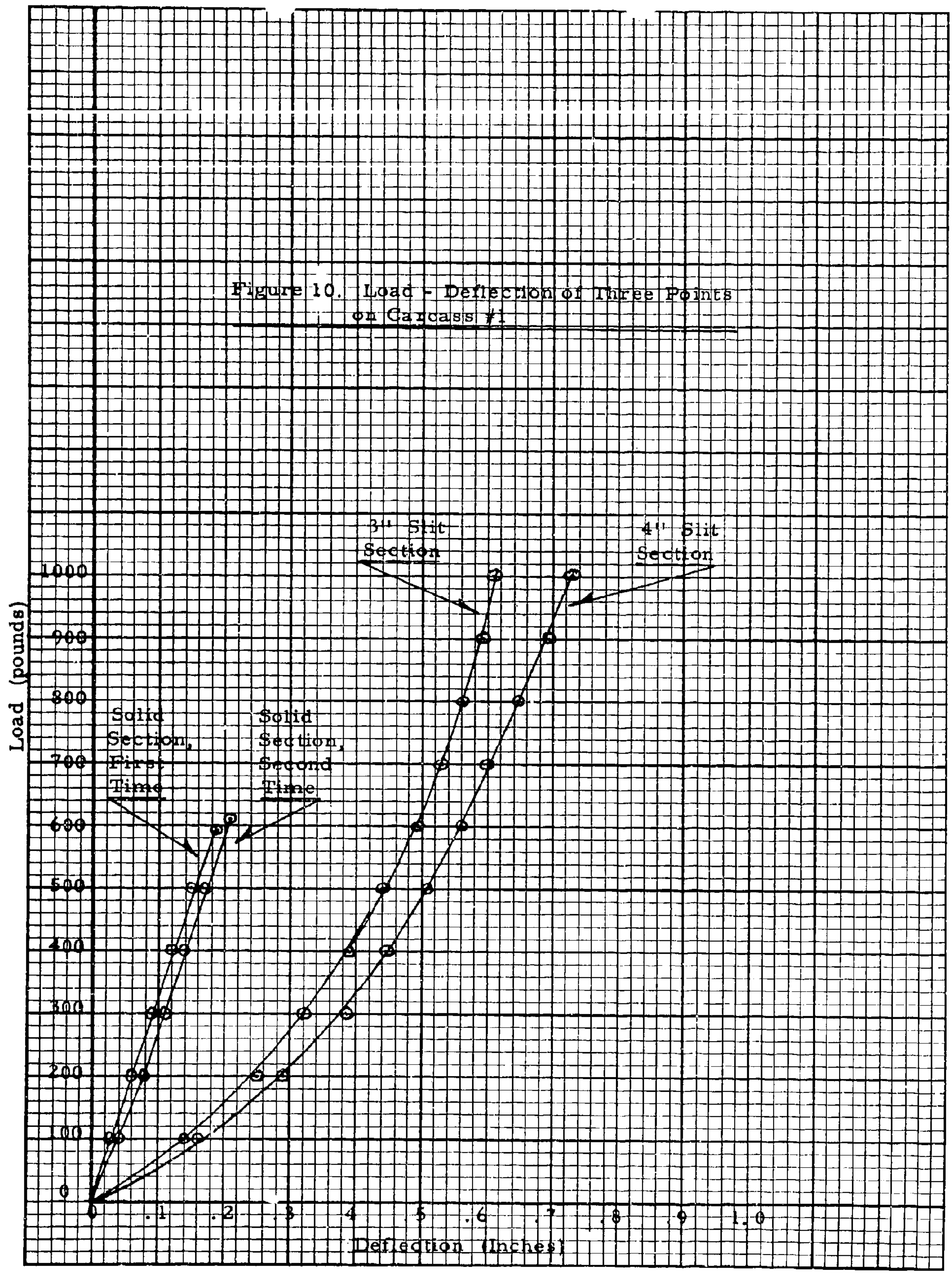


Figure 10. Load - Deflection of Three Points
on Carcass #1
3" Slit
Section
4" Slit
Section
Solid
Section,
First
Time
Solid
Section,
Second
Time
Load (pounds)
1000
900
800
700
600
500
400
300
200
100
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
Deflection (Inches)

| | |
|---|---|
| Footprint Area: | 8.7 square inches |
| Deflection: | .18 inches |
| Load: | 597 pounds |

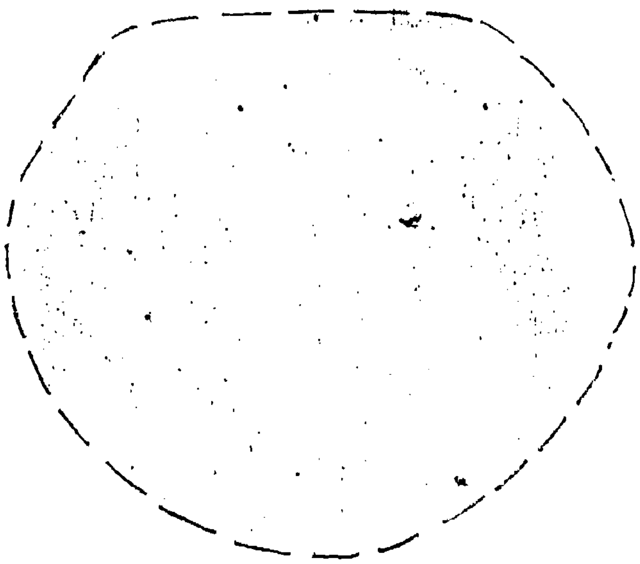
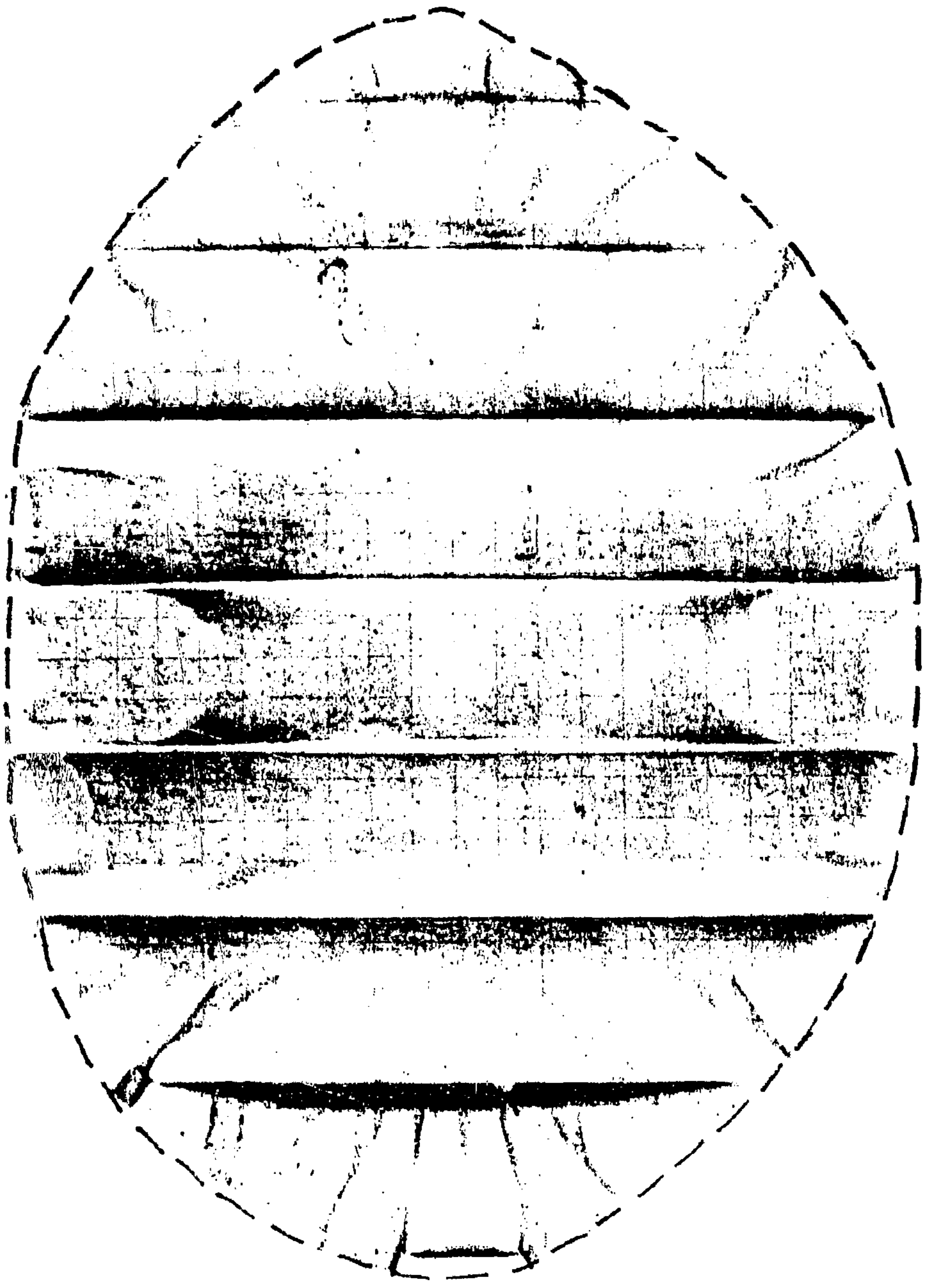
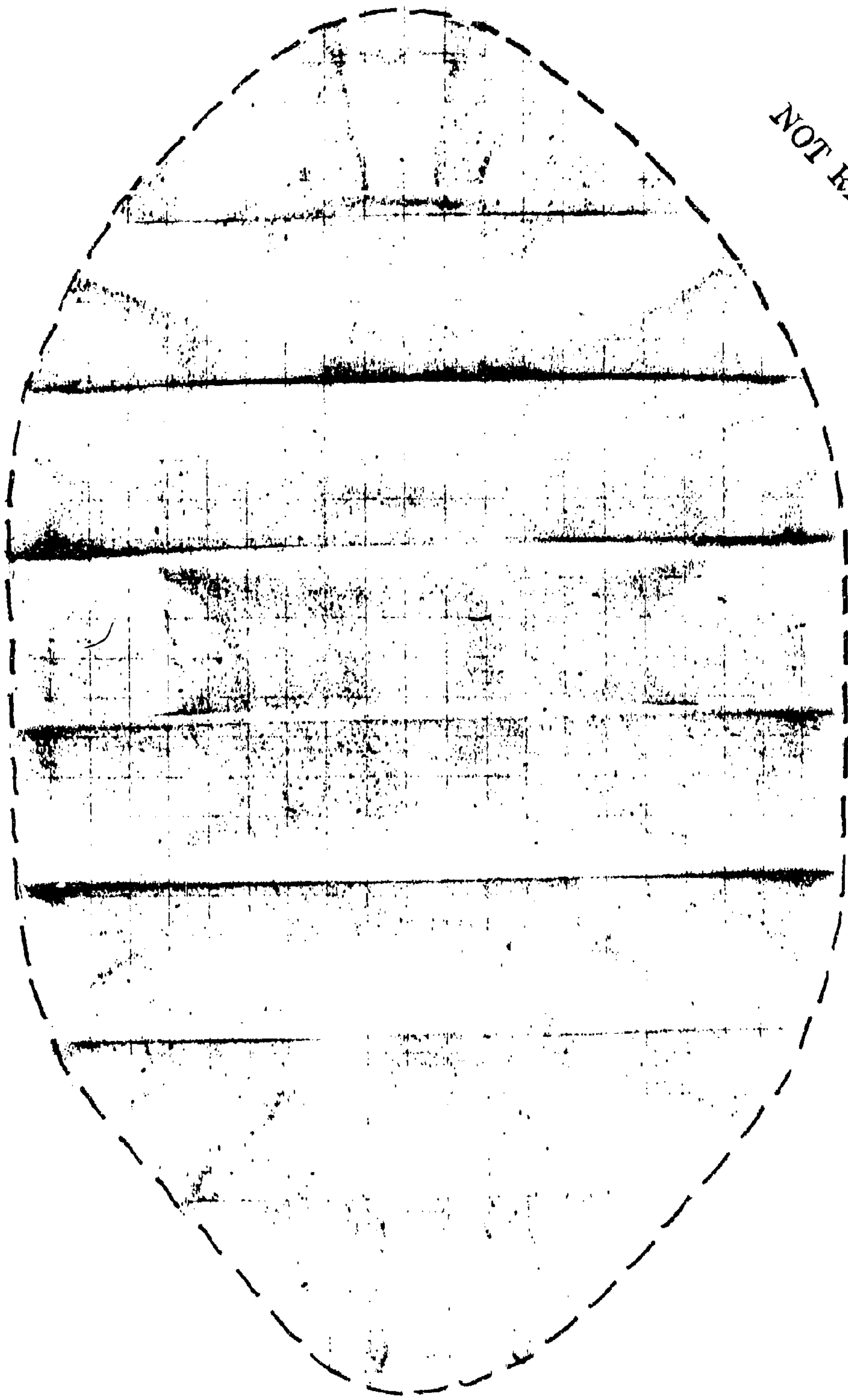


Figure 11a. Footprint Area for Solid Section, Carcass #1



| | |
|---|---|
| Footprint Area: | 32.5 square inches |
| Deflection: | .61 inches |
| Load: | 1,000 lbs. |

Figure 11b. Footprint Area for Three-Inch Slit Section, Carcass #1




| | |
|---|---|
| Footprint Area: | 35.4 square inches |
| Deflection: | .73 inches |
| Load: | 1,000 pounds |

Figure 11c. Footprint Area for Four-Inch Slit Section, Carcass #1

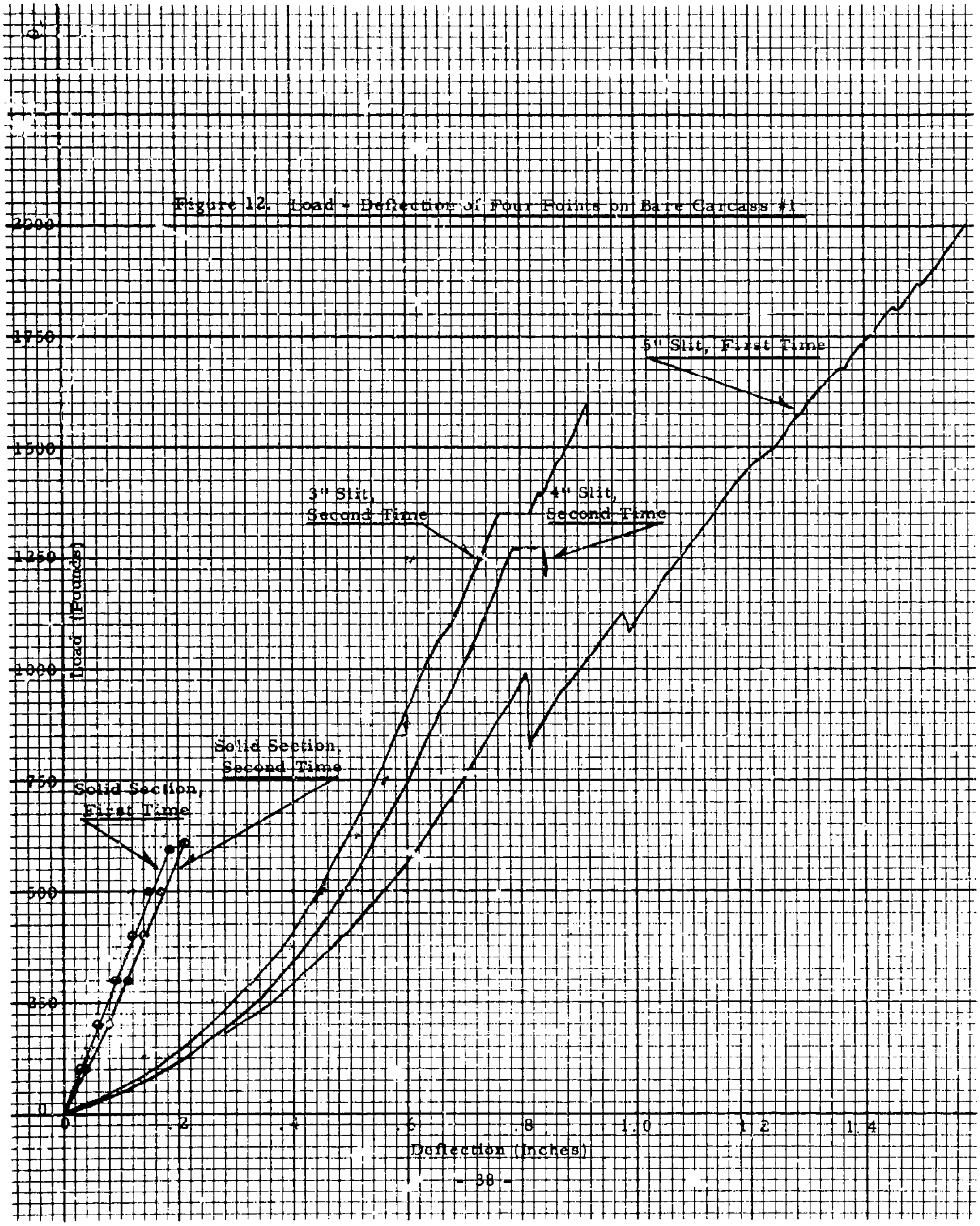
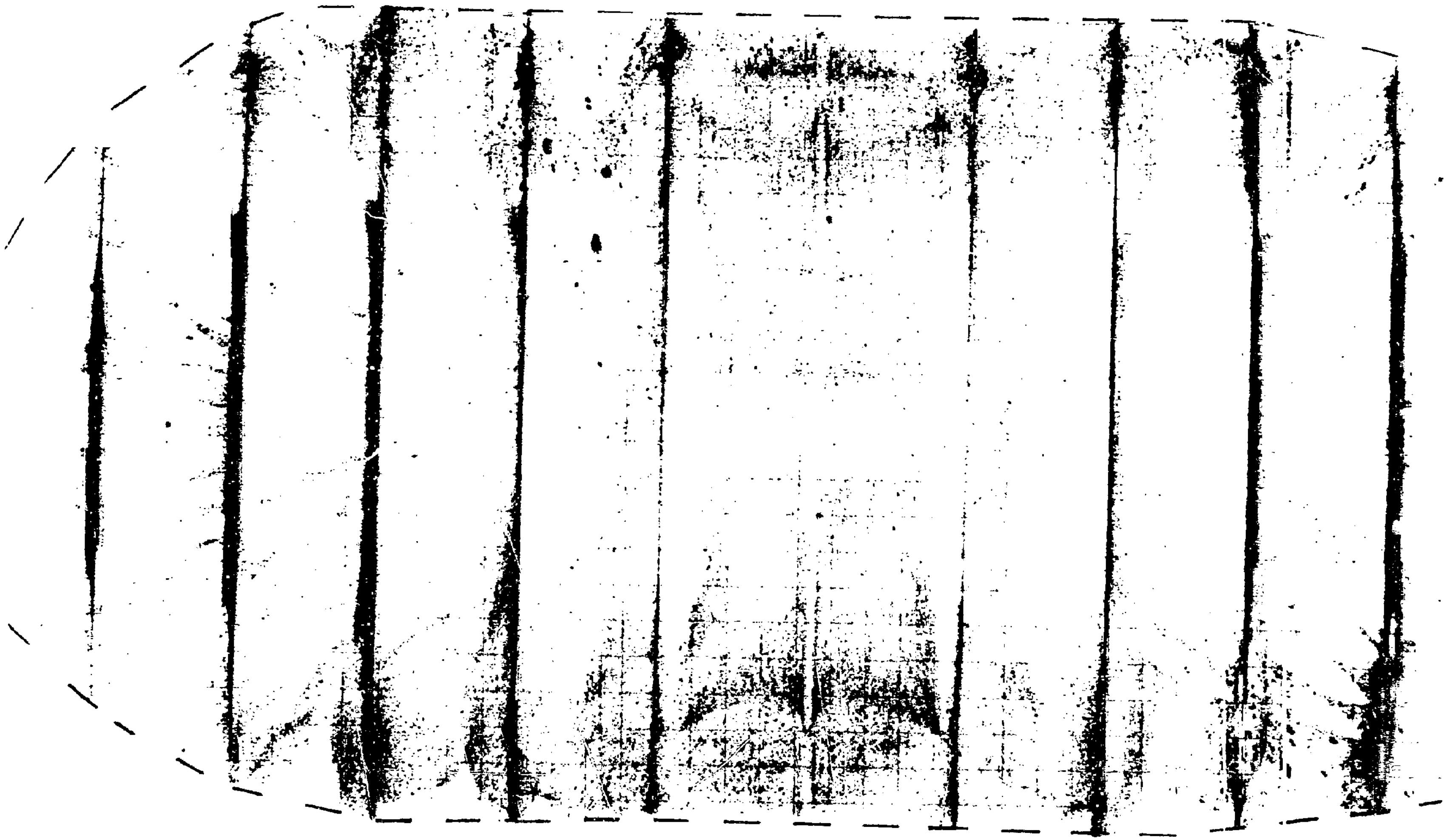
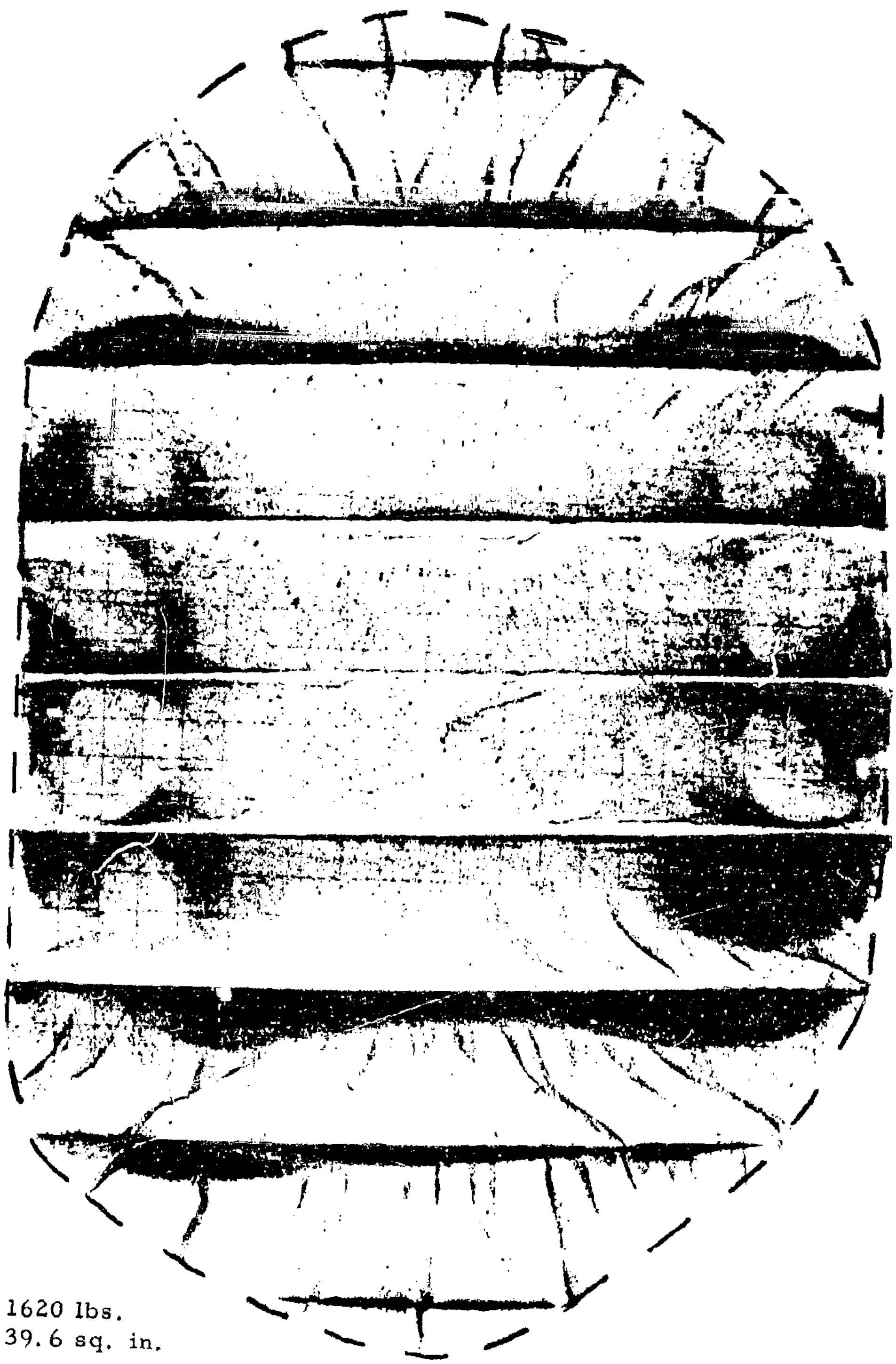


Figure 12. Load - Deflection of Four Points on Bare Carcass #1
2000
1750
1500
1250
1000
750
500
250
0
Load (Pounds)
5" Slit, First Time
3" Slit, Second Time
4" Slit, Second Time
Solid Section, Second Time
Solid Section, First Time
0
.2
.4
.6
.8
1.0
1.2
1.4
Deflection (Inches)



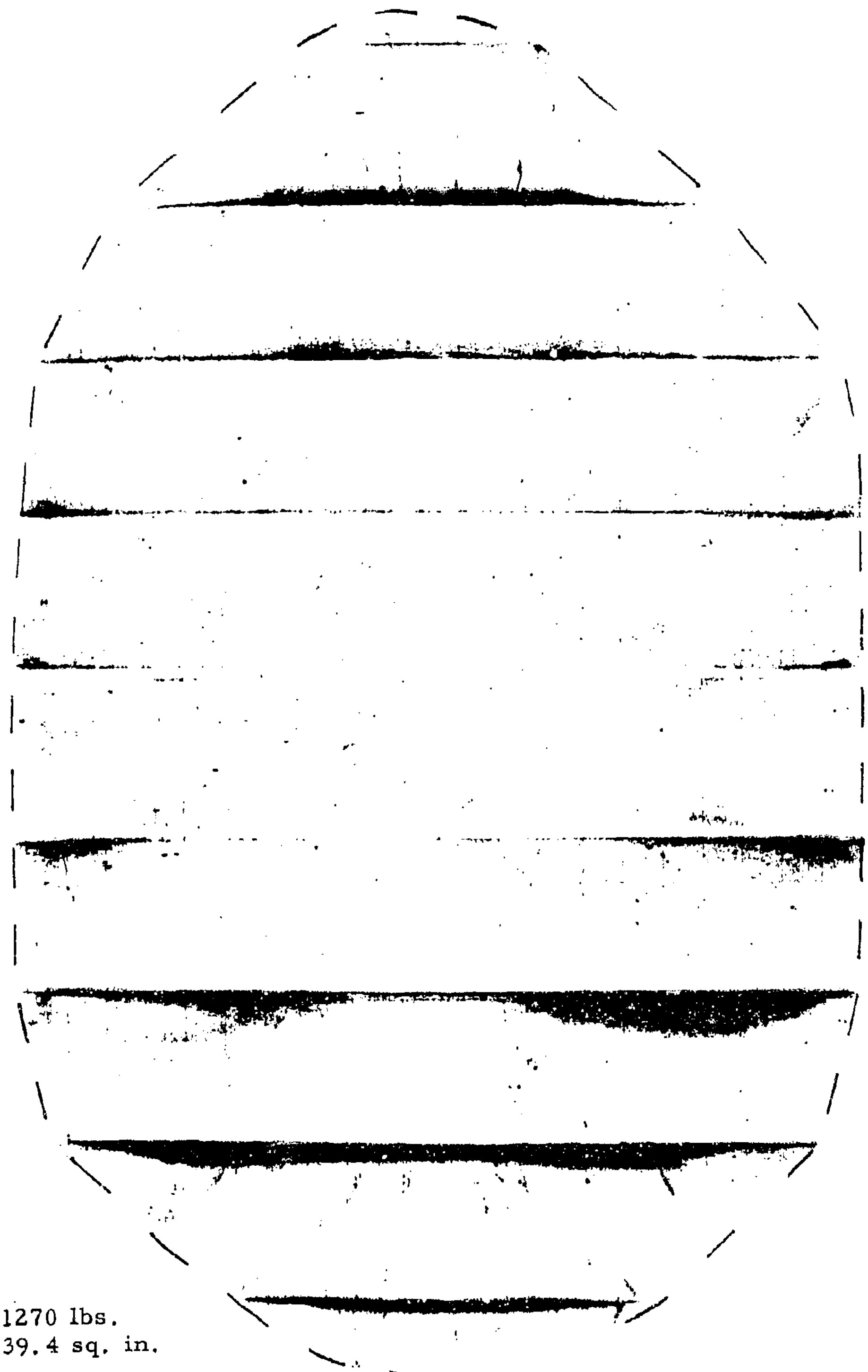
Load: 2000 lbs.
Area: 53.8 sq. in.

Figure 13a. Footprint Area for 1 inch x 5 inch Slit Section; No Rubber; First Loading Carcass #1



Load: 1620 lbs.
Area: 39.6 sq. in.

Figure 13b. Footprint Area for 1 inch x 3 inch Slit Section; No Rubber; Second Loading; Carcass #1



Load: 1270 lbs.
Area: 39.4 sq. in.

Figure 13c. Footprint Area for 1 inch x 4 inch Slit Section; No Rubber; Second Loading; Carcass #1

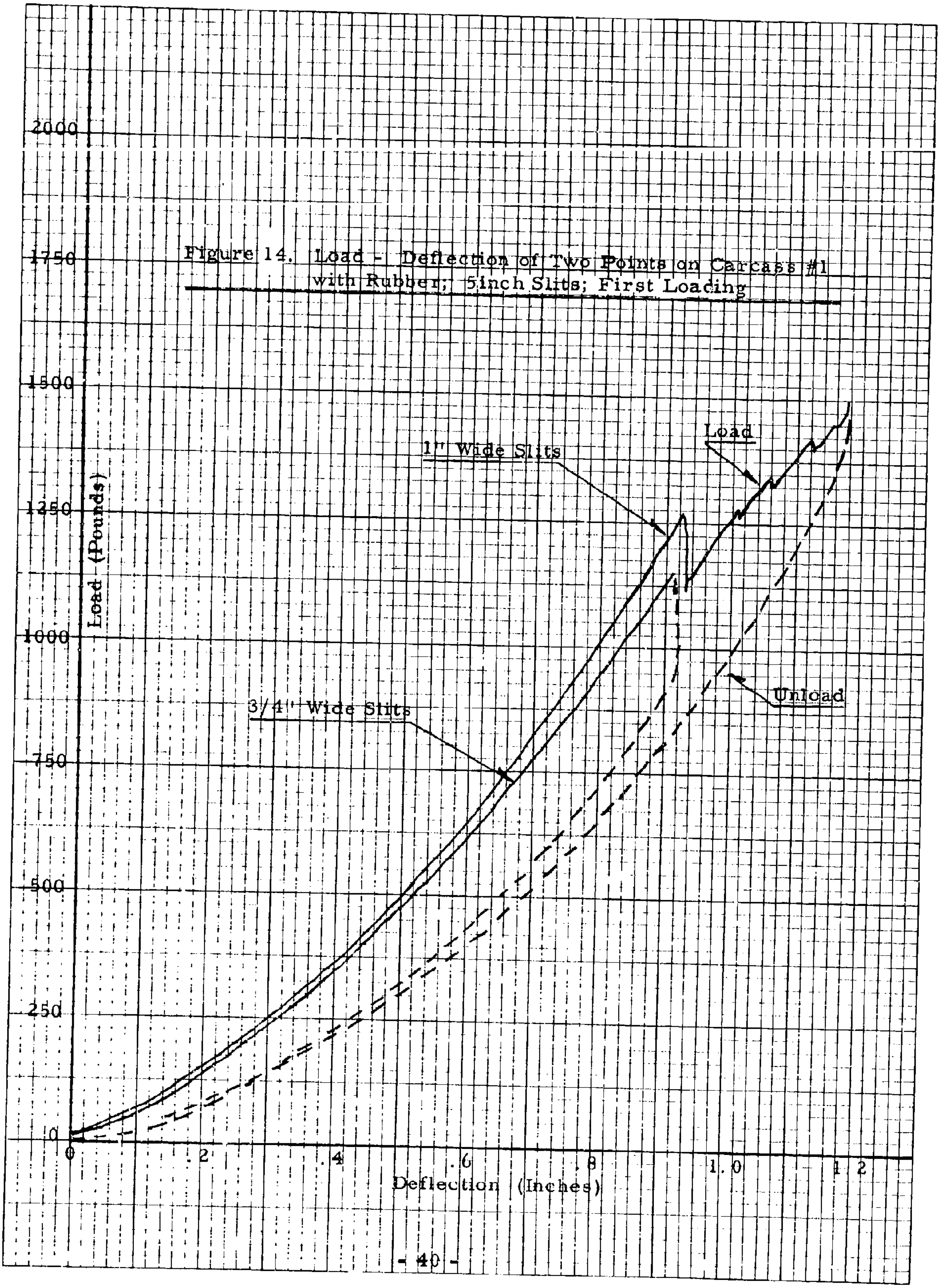


Figure 14. Load - Deflection of Two Points on Carcass #1 with Rubber; 5inch Slits; First Loading
Load (Pounds)
2000
1750
1500
1250
1000
750
500
250
0
Deflection (Inches)
0
.2
.4
.6
.8
1.0
1.2
1" Wide Slits
3/4" Wide Slits
Load
Unload

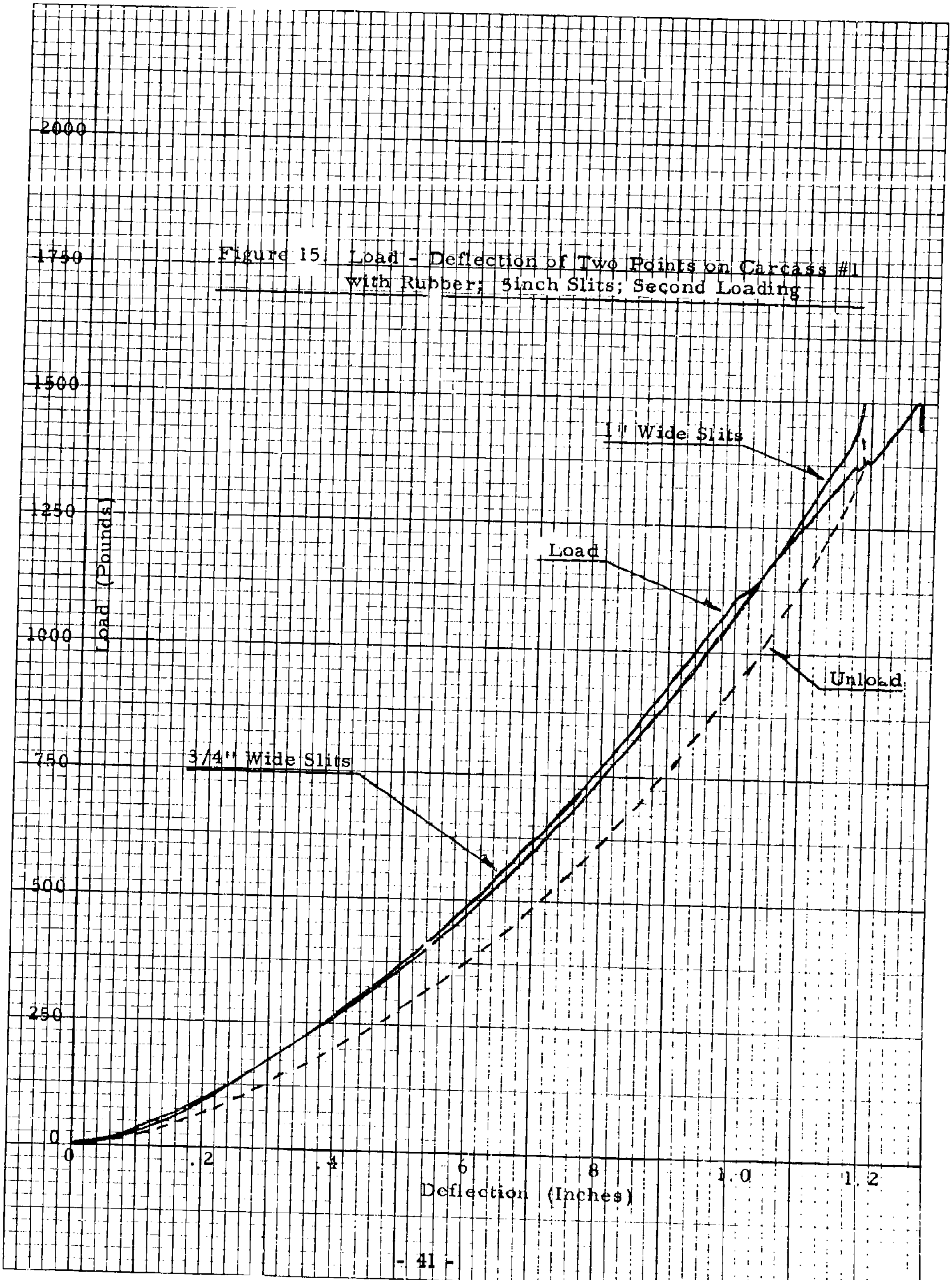


Figure 15. Load - Deflection of Two Points on Carcass #1 with Rubber; 5inch Slits; Second Loading
1" Wide Slits
Load
Unload
3/4" Wide Slits
Load (Pounds)
2000
1750
1500
1250
1000
750
500
250
0
0
.2
.4
.6
.8
1.0
1.2
Deflection (Inches)

Figure 16. Load - Deflection of Two Points on Carcass #1 with Rubber; 5 inch Slits; Third Loading

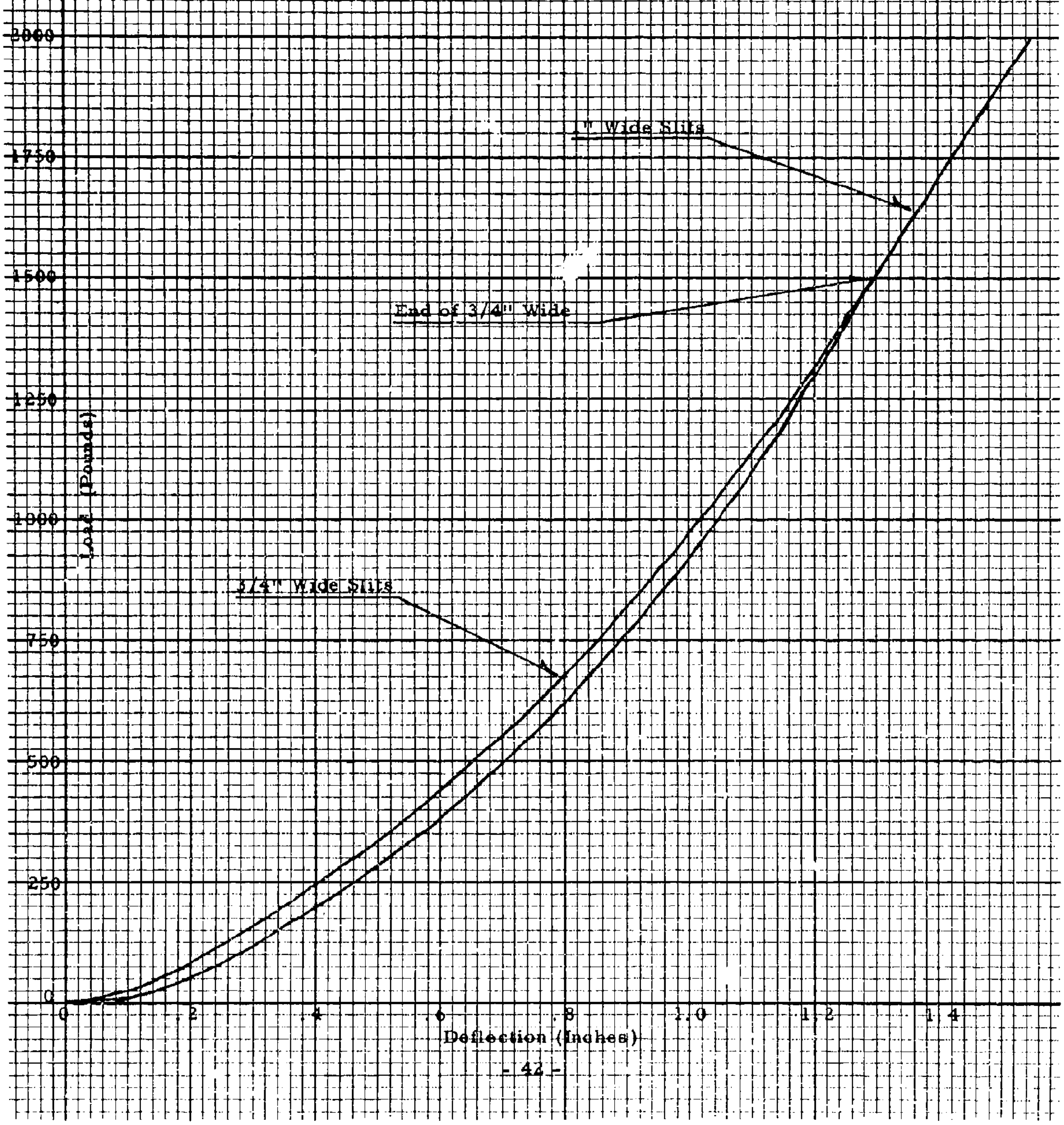
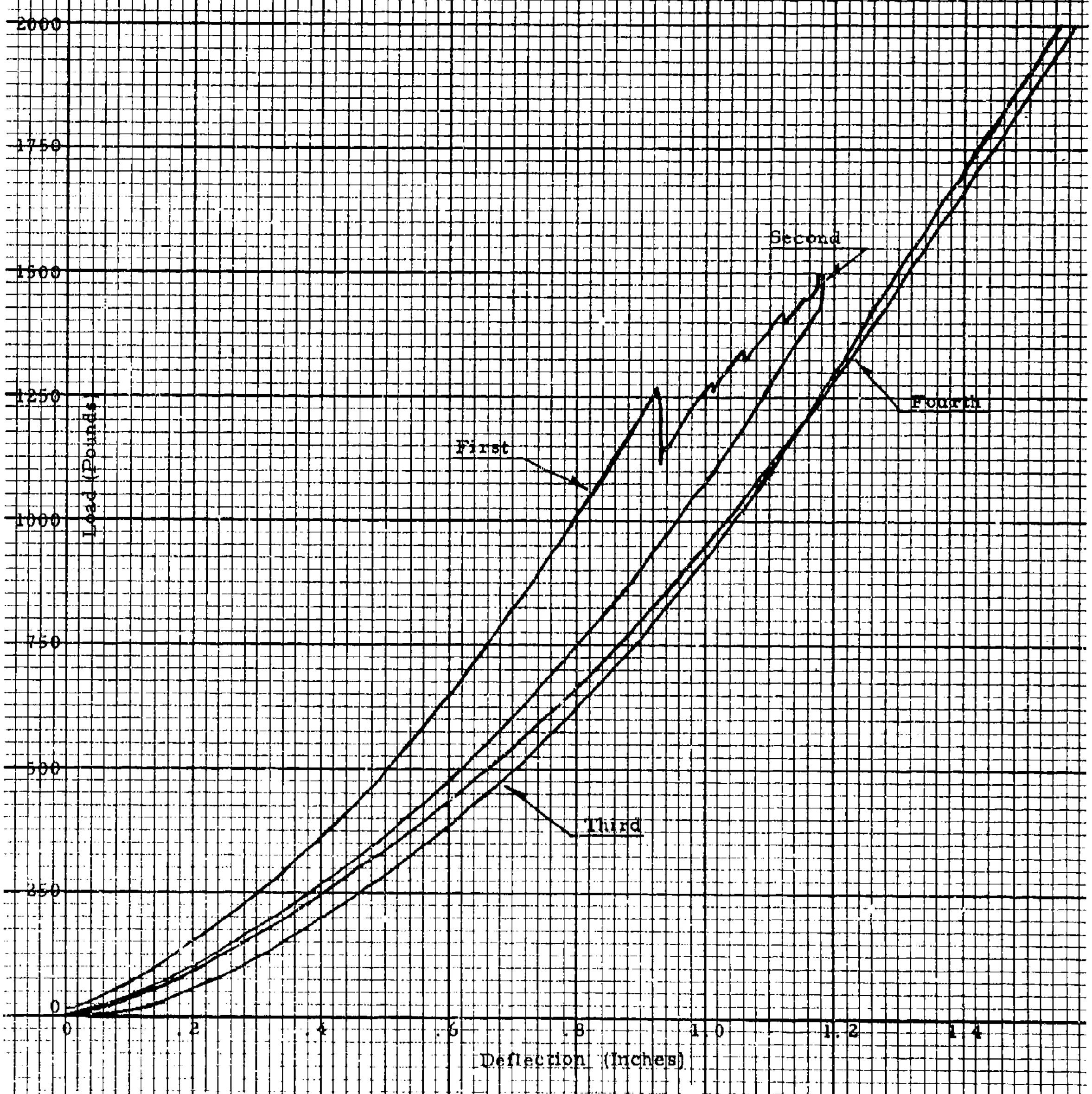


Figure 17. Four Successive Loadings on Carcass #1 with Rubber and 1 inch x 5 inch Slits



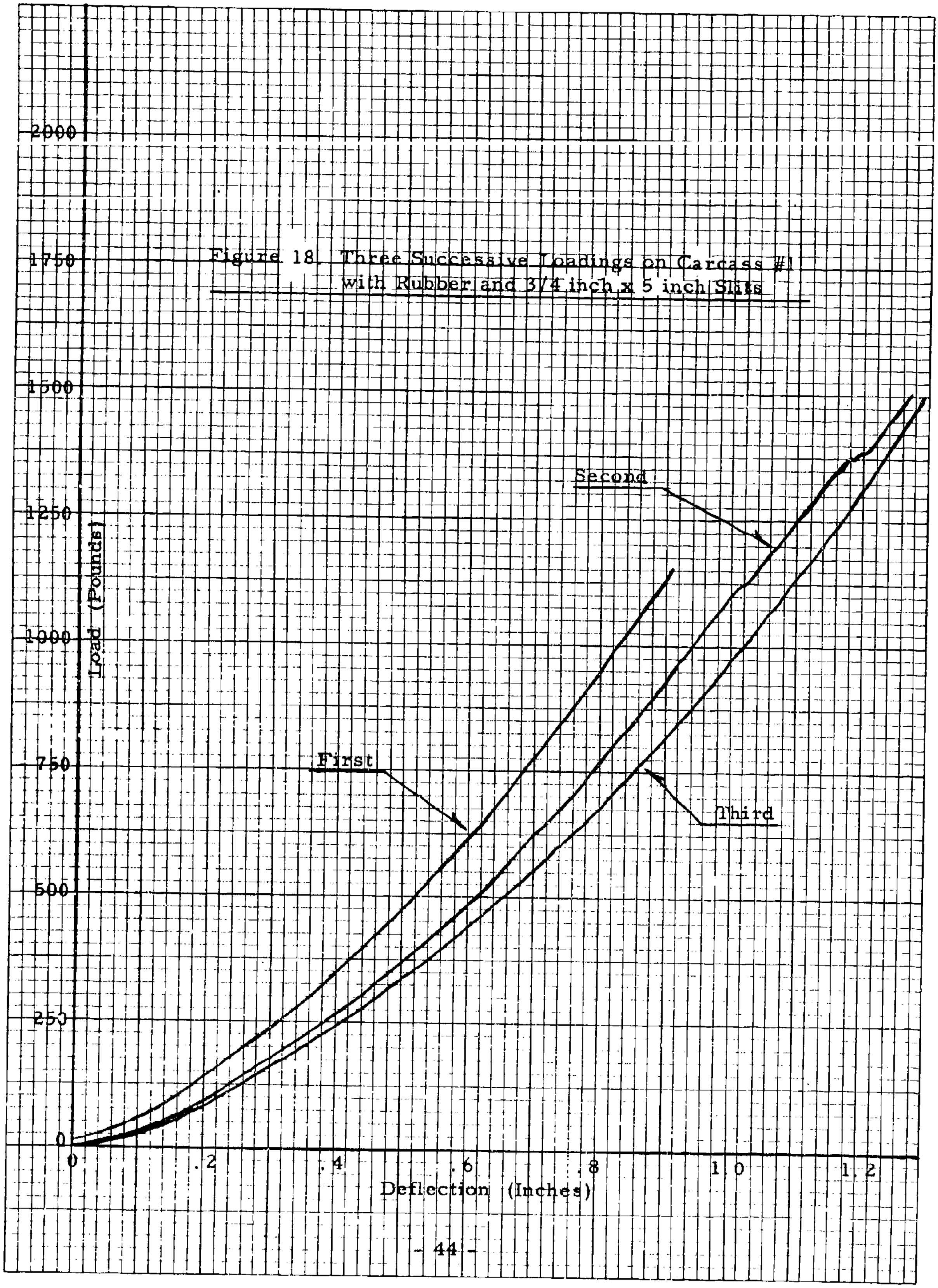



Figure 18. Three Successive Loadings on Carcass #1 with Rubber and 3/4 inch x 5 inch Slits

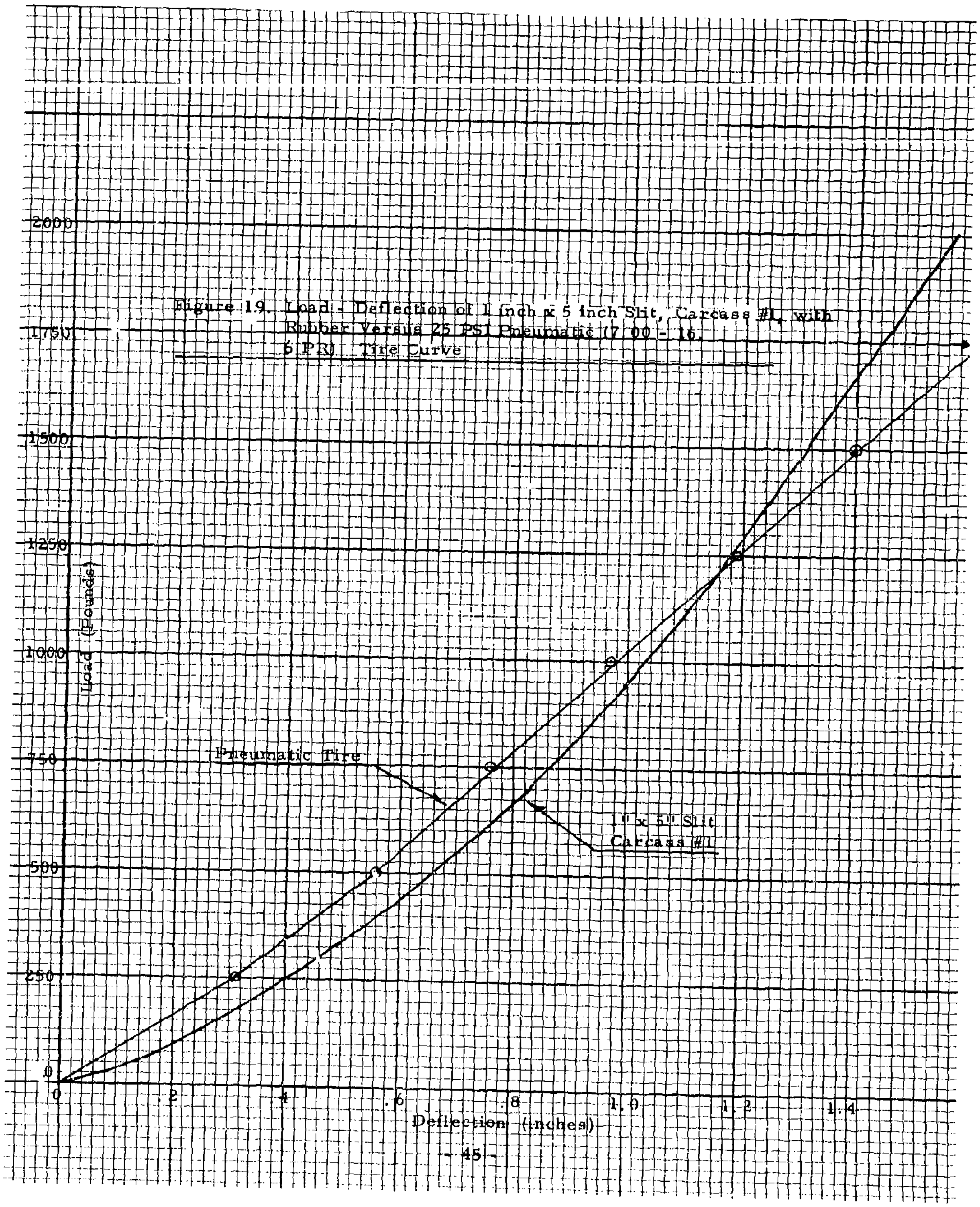



Figure 19. Load - Deflection of 1 inch x 5 inch Slit, Carcass #1, with Rubber Versus 25 PSI Pneumatic (7.00 - 16, 6 PR) Tire Curve

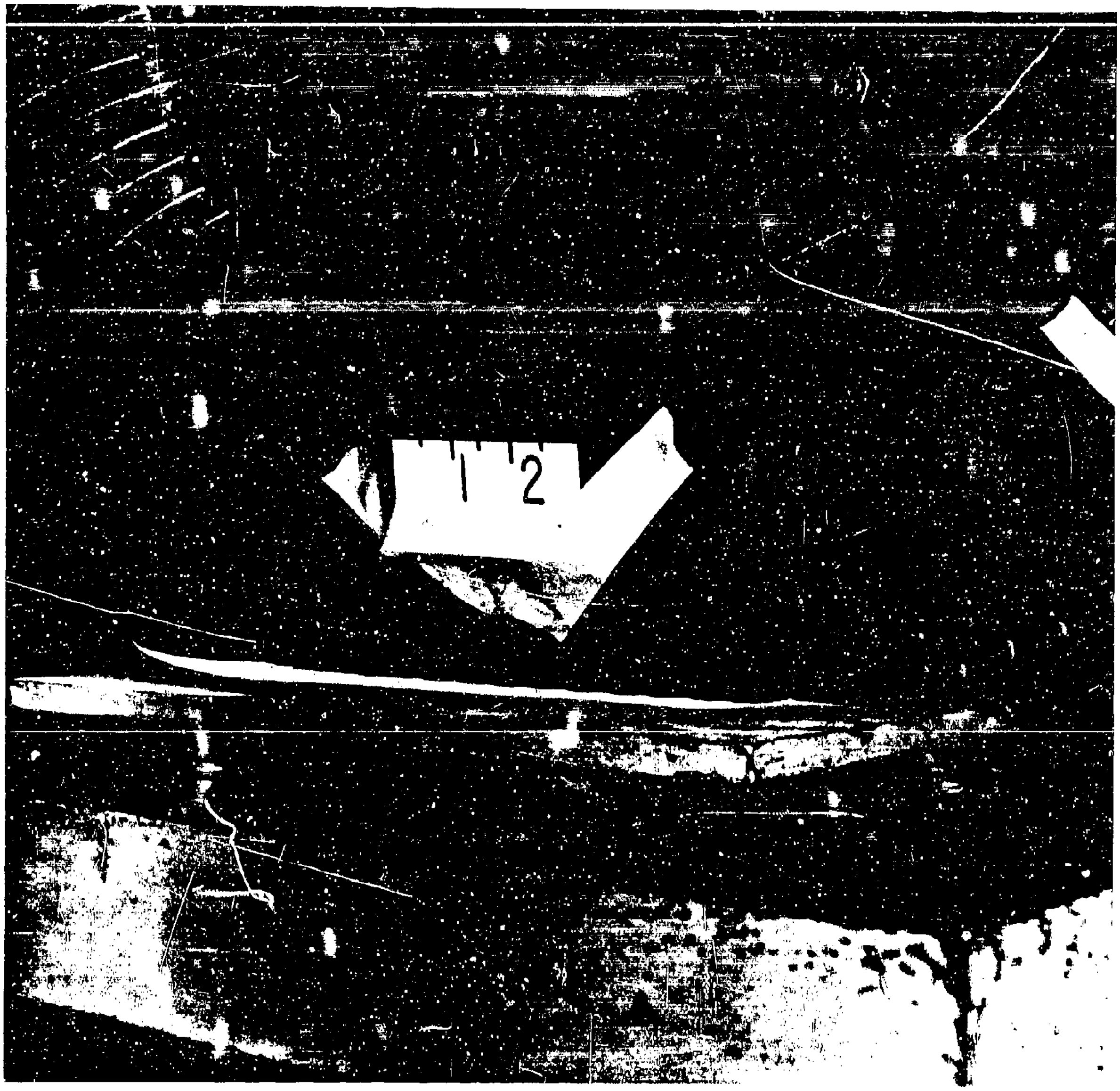



Figure 20. Carcass #1 under 2,000 Lb. Load

Load: 2000 lbs.
Area: 47.0 sq. in.
Figure 21. Carcass #1 Footprint Area for 1 inch x 5 inch Slit Section; with Rubber; Fourth Loading

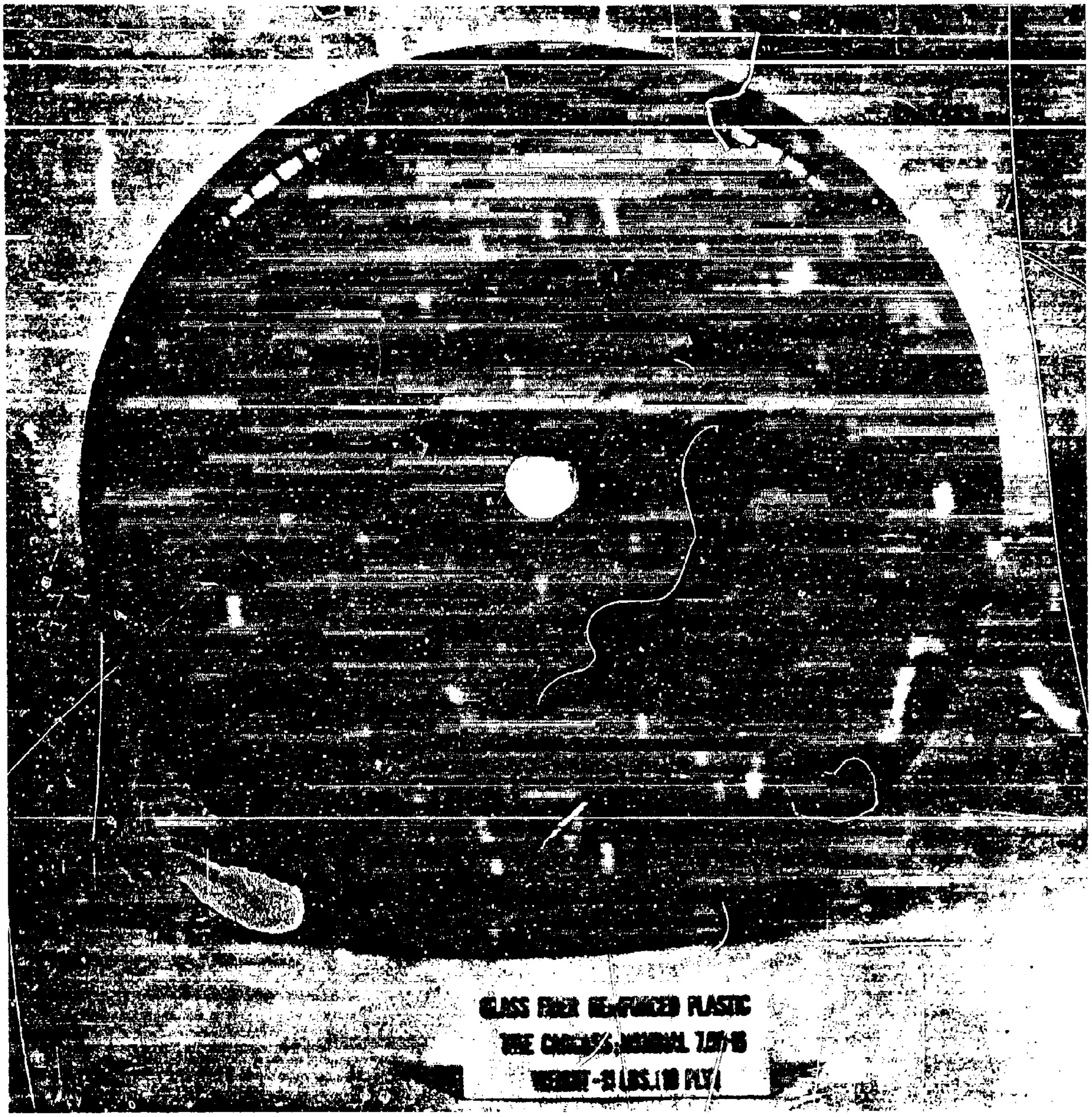


Figure 22. Tire #1, Bare Carcass

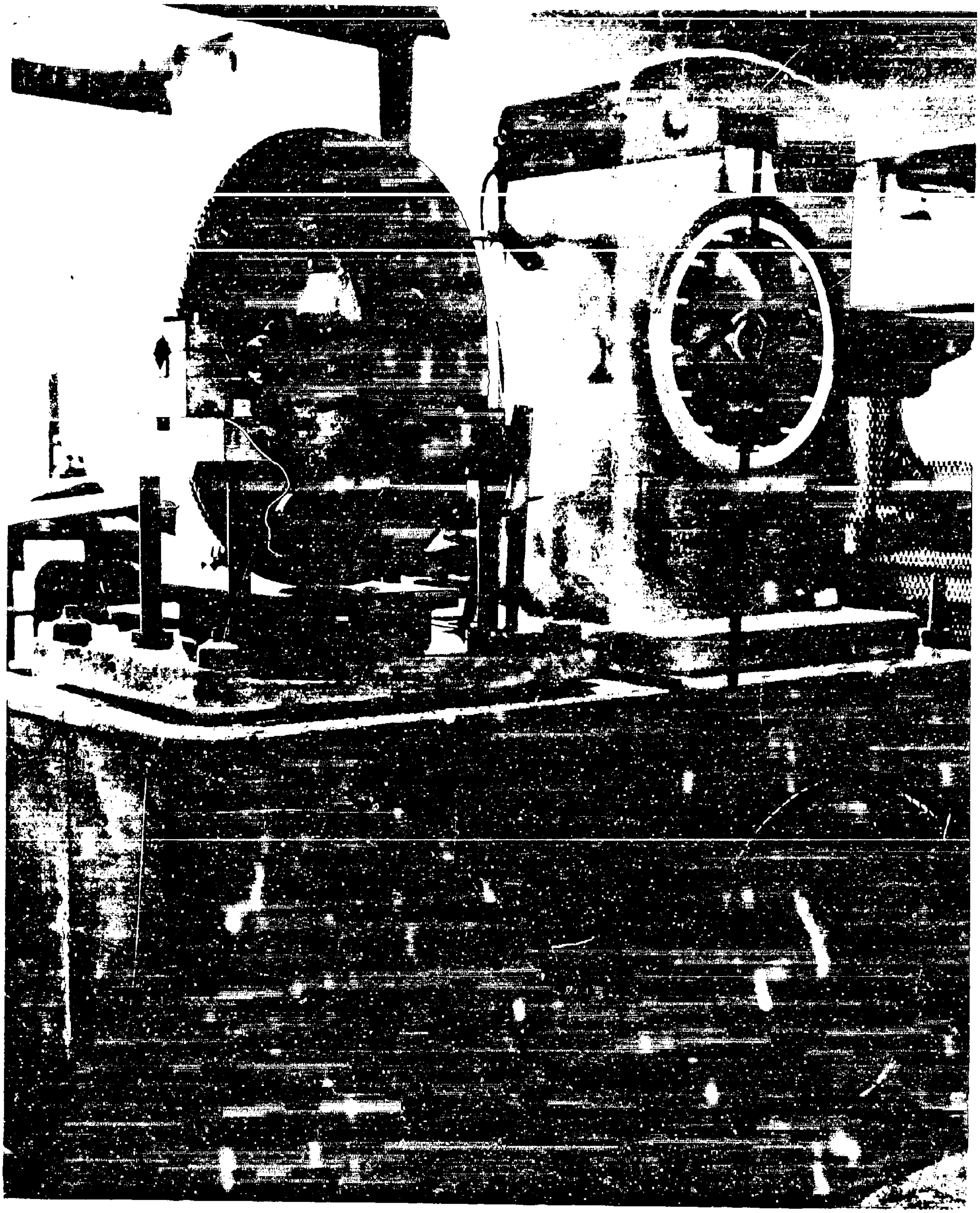


Figure 23. Tire #1 under Static Load

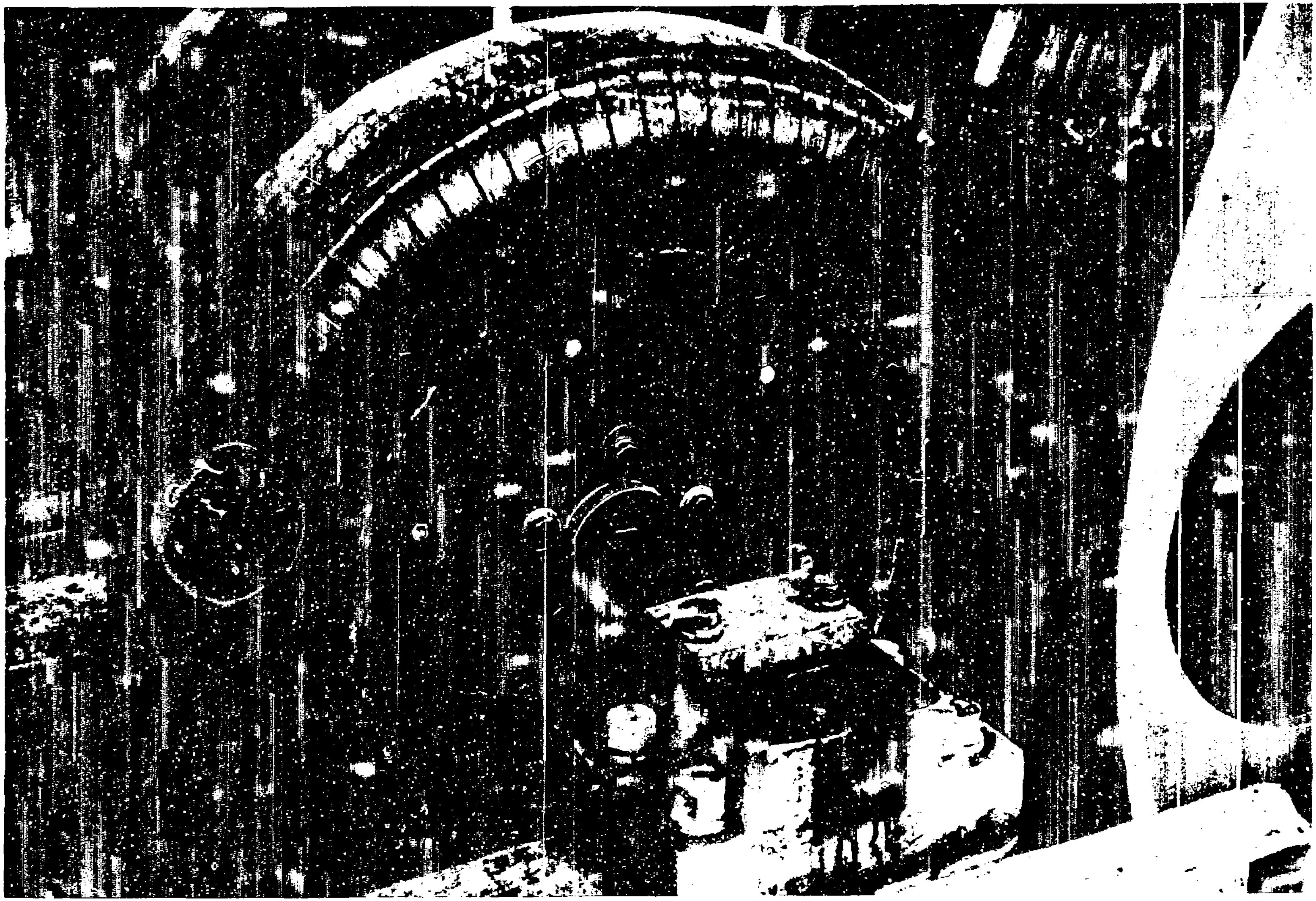


Figure 24. Tire #2 on TACOM Indoor Wheel

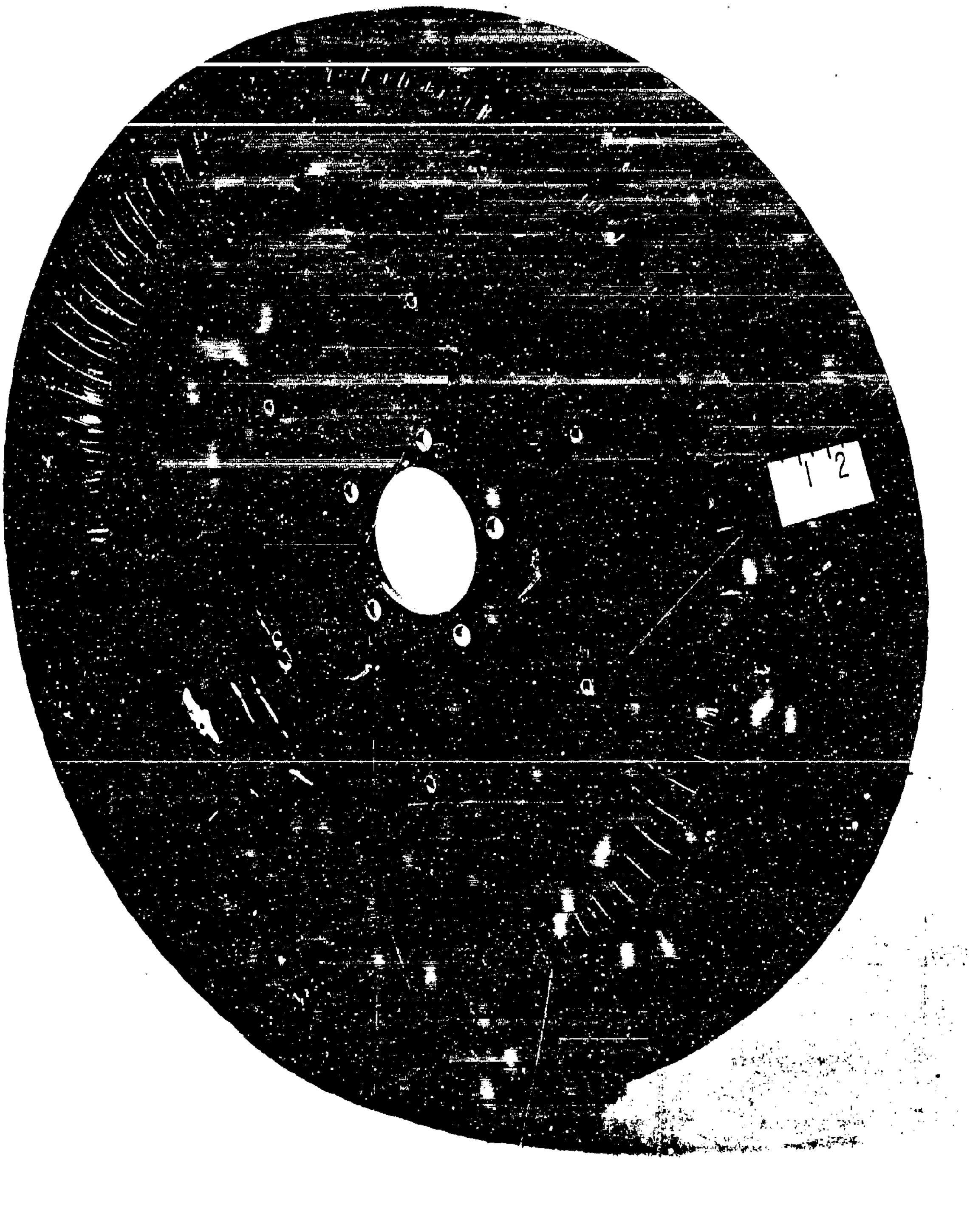



Figure 25. Tire #4

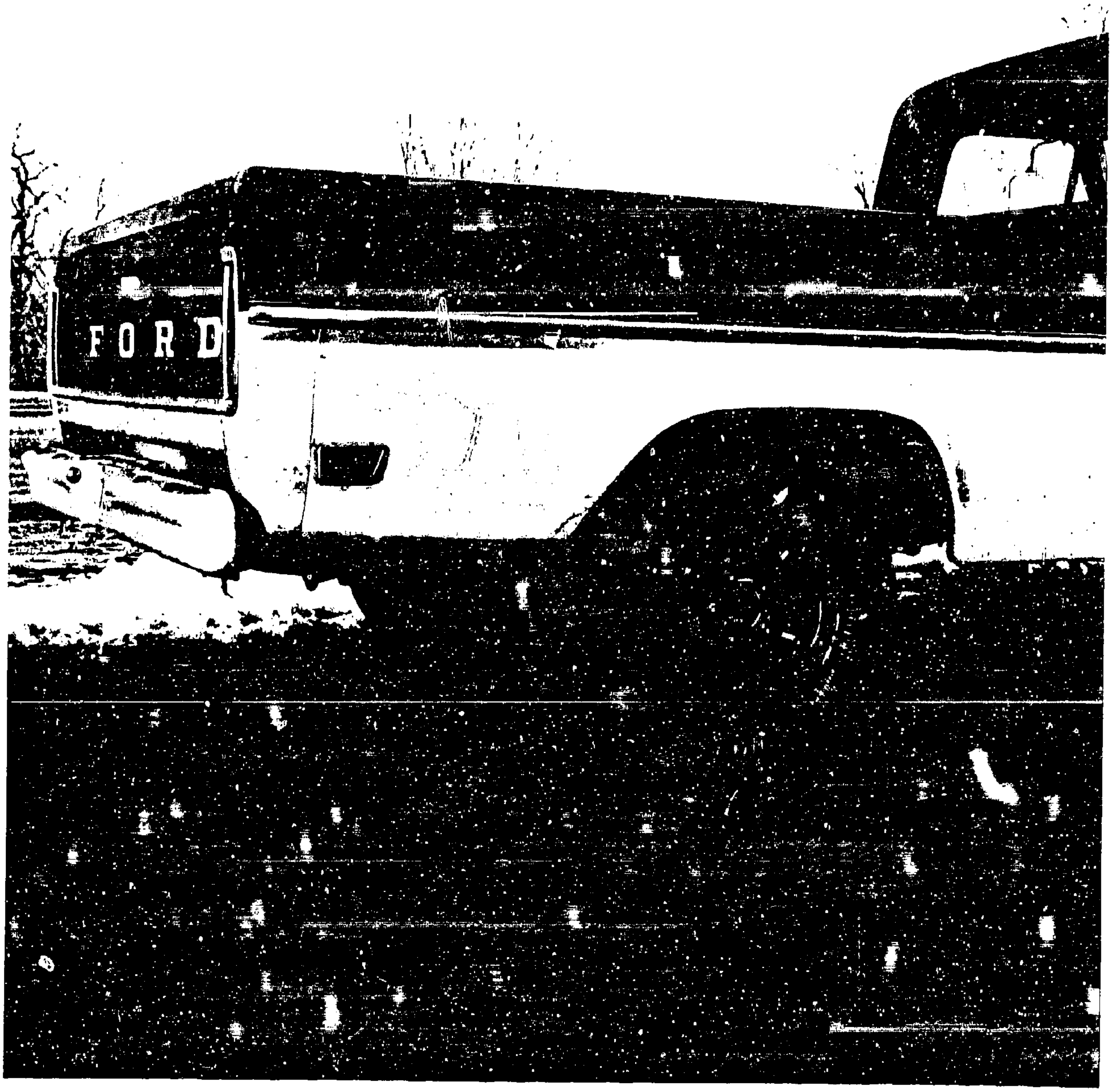



Figure 26. Tire #4 Mounted on Pickup Truck

# APPENDIX I

## MEMBRANE SHELL THEORY

## MEMBRANE SHELL THEORY

The membrane shell theory has been used by Lauterbach and Ames [1], Walston and Ames [2], Biederman [3] and, no doubt, others to analyze pneumatic rubber tires. In particular, reinforcing cord forces have been predicted in tires whose actual deflected shapes were measured.

The approximate shape of interest is a toroid or modification of a toroid in which a surface or membrane is generated by rotating a closed curve about an axis external to the closed curve. It is perhaps more correct to say that this shape can be easily described mathematically but it is not completely descriptive of a loaded glass fiber reinforced plastic (GFRP) toroid tire since there will be some departure from a symmetrical form in the footprint region.

A compact and lucid exposition of the theory of membrane shells or thin shells is given by Wang [4] or Timoshenko and Woinowsky-Kreiger [5]. The details will not be reproduced here. Some of the assumptions will be outlined since they can be limiting on the application of the theory. A thin shell is said to be described by its middle surface, i.e., the surface which lies midway between the actual inner and outer shell boundaries. When the thickness is much smaller than any of the other shell dimensions we have a thin shell. The membrane theory further requires that all bending effects are to be ignored. Another way of saying this is that no changes in shell curvature occur during loading or that lines normal to the middle surface originally remain normal during loading and do not undergo relative rotation

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(1) Lauterbach, H. G. and Ames, W. F., Textile Research Journal, Vol. 29, No. 11, 1959, pp 890-900.

(2) Walston, W. N. and Ames, W. F., Design and Analysis of Inflated Reinforced Membranes, Department of Mechanical Engineering, University of Delaware, Technical Report No. 22, August 1963.

(3) Biederman, V. L. "Calculation of Profile and Stresses in Elements of Pneumatic Tires under Inflation Pressure," (Translation of paper in Russian with incomplete reference) 1949.

(4) Wang, C. T., Applied Elasticity, McGraw-Hill, 1953, Chap. 12, pp 310-340.

(5) Timoshenko, S. and Woinowsky-Krieger, S., Theory of Plates and Shells, McGraw-Hill, 1959, Chap. 14, pp 429-466.

during loading. Since stresses are assumed to be constant through the thickness at any point, the quantities dealt with are stress resultants or the summation extending through the thickness and along a unit width. The only normal stresses and shearing stresses considered are those which are parallel to the middle surface. Finally, the deflections must be small enough that the shape of the shell is not altered appreciably.

The membrane shell theory has one great advantage in that the three stress resultants or shell forces are statically determinable. This means, since there are three differential equations of equilibrium, that for known shape, applied forces, and boundary conditions, the shell forces can be determined from the equilibrium equations. No specification of the material properties is necessary.

As can be seen from the above, this analysis applies to monolithic or continuous shells and not to the segmented carcass design adopted eventually in this program. Even for a continuous carcass, the applicability of the membrane shell theory is questionable. First, bending effects in the region near the boundary of the footprint may not be negligible. Second, the theory requires that the loaded and deflected carcass be treated as if it were undeflected. Thus, shell forces could be calculated which are valid only for points away from the footprint or away from the rim. These latter are probably the regions of greatest stress.

Since the stresses could not be calculated, it was decided that a carcass should be made and loaded to determine stress-strain characteristics at various points in a continuous GFRP toroid. However, at this point in the program a satisfactory process had not been developed for winding a carcass with roving, which was the material originally intended for use. Therefore, it was decided to proceed on the assumption that a testable quality carcass could be wound using two-inch-wide glass fabric tape.

# APPENDIX II

## GFRP CARCASS PREPARATION PROCEDURE

The general process for making GFRP carcasses throughout this program was as follows:

(1) Make two sand-PVA half mandrels. Bond the two halves together with PVA.

(2) Place mandrel in winder and wind on PVA tape.

(3) Make 25 spools of wet prepreg roving. Each spool in each set of five contains exactly the same number of turns.

(4) Place one set of five spools in the winder. Tension each spool and tie the five ends onto the mandrel.

(5) Wind prepreg onto the mandrel for two revolutions of the mandrel.

(6) Repeat Items (4) and (5) four times for a total of ten ply reversing the direction of travel of the mandrel between each double ply, and staggering the five tie-on locations around the mandrel.

(7) Precure the carcass for two hours at 185° F.

(8) Cut several of the desired slits and/or holes through the carcass and mandrel.

(9) Using water, remove the mandrel and PVA tape through the slits.

(10) Postcure the carcass for four hours at 300° F.

(11) Finish cutting the desired number of slits.

(12) Prepare carcass surface to receive rubber.

(13) Apply desired rubber and cord, wrap with PVA, and vulcanize in hot air for appropriate time at 300° F.

(14) Apply premolded GFRP split rim, or mold rim directly to carcass.

(15) Machine lug holes and hub in rim, and balance tire.

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13. ABSTRACT


The program sought to provide adequate data on which to base a judgment of the probability of success in producing a satisfactory glass fiber reinforced plastic pressureless tire by the filament winding method. The tire sought represents an entirely new and unique concept in automotive tires, and would be impossible to deflate.

A process was developed to produce a preliminary model of a 7.00 x 16 tire. Several tire configurations were wound and tested statically, and dynamically on an indoor wheel at USATACOM. The last carcass made ran for 239 miles at 850 pounds load; most of the test was conducted at 40 miles per hour.

The feasibility of a glass fiber reinforced plastic pressureless tire was demonstrated.


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| Non-pneumatic Tires | | | | | | |
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